Underwater Wireless Networking Techniques

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INTRODUCTION

Underwater sound has probably been used by marine specimens for millions of years as a communication capability among the members of a same species. It is said that in 1490, Leonardo Da Vinci wrote the following sentence: "If you cause your ship to stop and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you" (Urick, 1983); being perhaps the first recorded experiments about hearing underwater sounds.

In 1826 on Lake Geneva, Switzerland, the physicist Jean-Daniel Colladon, and his mathematician friend Charles-Francois Sturm, made the first recorded attempt to determine the speed of sound in water. In their experiment, the underwater bell was struck simultaneously with ignition of gunpowder on the first boat. The sound of the bell and flash from the gunpowder were observed 10-miles away on the second boat. The time between the gunpowder flash and the sound reaching the second boat was used to calculate the speed of sound in water. Colladon and Sturm were able to determine the speed of sound in water fairly accurately with this method. (Colladon, 1893).

This experiment on sound propagation through water laid the foundation for underwater acoustic technology, which paved the way for the development of this technology up to our days. In 1906, Lewis Nixon invented the very first sonar-type listening device, increasing the demand of this technology during World War I to detect submarines. In 1915, the physicist Paul Langévin and the engineer Constantine Chilowski, invented the first sonar-type device for detecting submarines, called an "echo location to detect submarines," using the piezoelectric properties of the quartz. He was too late to offer any help to the war effort; however, Langévin's work heavily influenced future sonar designs.

After using underwater sound technology for measuring the proximity to the shore and other ships, researchers soon realized that, if the sound device was pointed down at the seafloor, the depth could be accurately determined. So, new applications of sonar devices were discovered, like active depth measuring (bathymetry), seafloor shape registering, search for geological resources (i.e., oil, gas, etc.), detecting and tracking fish banks, submarine archaeology, and so forth.

Although the underwater acoustic applications were mainly focused in ranging applications, exploration of seafloor and fishery by means of sonar devices, the interest in underwater multipoint communications was stressed in the 1990's, where synoptic, spatially sampled oceanographic surveillance has provided an impetus to the transfer of networked communication technology to the underwater environment. One of the former deployments was the autonomous oceanographic surveillance network (AOSN), supported by the US Office of Naval Research (ONR) (Curtin, Bellingham, Catipovic, & Webb, 1993). It calls for a system of moorings, surface buoys, underwater sensor nodes, and autonomous underwater vehicles (AUVs) to coordinate their sampling via an acoustic telemetry network.

BACKGROUND

Wireless networking technologies have experienced a considerable development in the last 15 years, not only in the standardization areas, but also in the market deployment of a bunch of devices, services, and applications. Among this plethora of wireless products, wireless sensor networks are exhibiting an incredible boom, being one of the technological areas with greater scientific and industrial development pace (Akyildiz, Sankarasubramaniam, & Cayirci, 2002). The interest and opportunity in working on wireless sensor network technologies is endorsed by (a) technological indicators like the ones published by MIT (Massachusetts Institute of Technology) in 2003 (van der Werff, 2003), where wireless sensor network technology was defined as one of the 10 technologies that will change the world, and (b) economic and market forecasts published by different economic magazines like (Rosenbush, Crockett, & Yang, 2004), where investment in wireless sensor network (WSN) ZigBee technology was estimated over 3.500 nillion dollars during 2007.

Recently, wireless sensor networks have been proposed for their deployment in underwater environments, where a lot of applications like aquiculture, pollution monitoring, offshore exploration, and so forth, would benefit from this technology (Cui, Kong, Gerla, & Zhou, 2006).

Despite having a very similar functionality, underwater wireless sensor networks (UWSNs) exhibit several architectural differences, with respect to the terrestrial ones, that are mainly due to the transmission medium characteristics (sea water) and the signal employed to transmit data (acoustic ultrasound signals) (Akyildiz, Pompili, & Melodia, 2006). Then, the design of appropriate network architecture for UWSNs is seriously hardened by the conditions of the communication system and, as a consequence, what is valid for terrestrial WSNs is perhaps not valid for UWSNs. So, a general review of the overall network architecture is required in order to supply an appropriate network service for the demanding applications in such an unfriendly submarine communication environment.

Major challenges in the design of underwater acoustic networks are:

- Battery power is limited and usually batteries can not be recharged because solar energy cannot be exploited;
- The available bandwidth is severely limited;
- The channel suffers from long and variable propagation delays, multipath and fading problems;
- Bit error rates are typically very high;
- Underwater sensors are prone to frequent failures because of fouling, corrosion, and so forth.

In the next section, we discuss the main issues in the design of efficient underwater wireless sensor networks. Following a bottom-to-top approach, we will review the network architecture, highlighting some critical design parameters at each of the different network layers, and how to overcome the limitations and problems introduced by UWSN environments.

UNDERWATER WIRELESS NETWORKING TECHNOLOGIES

Basically, a UWSN is formed by the cooperation among several nodes that establish and maintain a network through the use of bidirectional acoustic links. Every node is able to send/receive messages from/to other nodes in the network, and also to forward messages to remote destinations in case of multihop networks. Every node may have one or several sensors that are actively recording environmental data that should be forwarded to special sink nodes, typically platforms or buoys at the surface. Sink nodes have communication channels to forward and/or locally store the collected data to the remote control station in the coast, typically through a radio frequency (RF) link.

So, the UWSN allows an interactive environment where scientists can extract real-time data from multiple distant underwater sensor instruments. After evaluating the obtained data, control messages can be sent to individual network nodes so the overall network can be adapted to changing situations.

Topology

In Partan, Kurose, and Levine (2006), taxonomy of UWSN regimes is proposed. They classify different UWSNs in terms of both spatial coverage and node density. For every kind of network topology, different architectural approaches have to be considered in order to improve the network performance (throughput, delay, power consumption, packet loss, etc.). So, it is important to design the network architecture taking into account the intended network topology.

Physical Layer: Acoustic Link

The most common way to send data in underwater environments is by means of acoustic signals, just like dolphins and whales use to do for communicating between them. Radio frequency signals have serious problems to propagate in sea water, as shown in Schill, Zimmer, and Trumpf (2004), being operative for radio-frequency only at very short ranges (up to 10 meters) and with low-bandwidth modems (tens of Kbps).When using optical signals, the light is strongly scattered and absorbed underwater, so only in very clear water conditions (often very deep) does the range go up to 100 meters with high bandwidth modems (several Mbps) and blue-green wavelengths.

Since acoustic signals are mainly used in UWSNs, it is necessary to take into account the main aspects involved in the propagation of acoustic signals in underwater environments, including (1) the propagation speed of sound underwater is around 1,500 m/s (5 orders of magnitude slower than the speed of light), and so the communication links will suffer from large and variable propagation delays and relatively large motion-induced Doppler effects; (2) phase and magnitude fluctuations lead to higher bit error rates compared with radio channels' behaviour, being mandatory the use of forward error correction codes (FEC); (3) as frequency increases, the attenuation observed in the acoustic channel