# UNDERWATER ACOUSTIC SENSOR NETWORKS: ARCHITECTURE, APPLICATIONS & CHALLENGES

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*Abstract :* In our earth 75% covered by water that could be rivers and ocean also. The underwater sensor network are enabling technology and become more and more popular for monitoring large scale of area in oceans. Ocean bottom sensor nodes can be used for oceanographic data collection, pollution monitoring, offshore exploration and tactical surveillance applications. Moreover, Unmanned or Autonomous Underwater Vehicles (UUVs, AUVs), equipped with sensors, will find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Underwater acoustic networking is the enabling technology for these applications. Underwater Networks consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area.

In this paper, several fundamental key aspects of underwater acoustic communications are investigated. Different architectures for two-dimensional and three-dimensional underwater sensor networks are discussed, and the underwater channel is characterized. we also discussed the applications. The main challenges for the development of efficient networking solutions posed by the underwater environment are detailed at all layers of the protocol stack. Furthermore, open research issues are discussed and possible solution approaches are outlined.

***IndexTerms*-Wireless Sensor Network, Acoustic, Underwater.**

## I. INTRODUCTION

Ocean bottom sensor nodes are deemed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration and tactical surveillance applications. Multiple Unmanned or Autonomous Underwater Vehicles (UUVs, AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a need to enable underwater communications among underwater devices. Underwater sensor nodes and vehicles must possess self-configuration capabilities, i.e., they must be able to coordinate their operation by exchanging configuration, location and movement information, and to relay monitored data to an onshore station. Wireless Underwater Acoustic Networking is the enabling technology for these applications. UnderWater Acoustic Sensor Networks (UW-ASN) consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. To achieve this objective, sensors and vehicles self-organize in an autonomous network which can adapt to the characteristics of the ocean environment.

Acoustic communications are the typical physical layer technology in underwater networks. In fact, radio waves propagate at long distances through conductive sea water only at extra low frequencies (30−300 Hz), which require large antennae and high transmission power. Optical waves do not suffer from such high attenuation but are affected by scattering. Thus, links in underwater networks are based on acoustic wireless communications [1].

The traditional approach for ocean-bottom or ocean column monitoring is to deploy underwater sensors that record data during the monitoring mission, and then recover the instruments [2].

This approach has the following disadvantages:

- Real time monitoring is not possible. This is critical especially in surveillance or in environmental monitoring applications such as seismic monitoring. The recorded data cannot be accessed until the instruments are recovered, which may happen several months after the beginning of the monitoring mission.
- No interaction is possible between onshore control systems and the monitoring instruments. This impedes any adaptive tuning of the instruments, nor is it possible to reconfigure the system after particular events occur.
- If failures or misconfigurations occur, it may not be possible to detect them before the instruments are recovered. This can easily lead to the complete failure of a monitoring mission.
- The amount of data that can be recorded during the monitoring mission by every sensor is limited by the capacity of the onboard storage devices (memories, hard disks, etc).

Therefore, there is a need to deploy underwater networks that will enable real time monitoring of selected ocean areas, remote configuration and interaction with onshore human operators. This can be obtained by connecting underwater instruments by means of wireless links based on acoustic communication.

Many researchers are currently engaged in developing networking solutions for terrestrial wireless ad hoc and sensor networks. Although there exist many recently developed network protocols for wireless sensor networks, the unique characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity and variable delays, require for very efficient and reliable new data communication protocols.

The main differences between terrestrial and underwater sensor networks can be itemized as follows:

- **Cost:** Underwater sensors are more expensive devices than terrestrial sensors.

- **Deployment**: The deployment is deemed to be more sparse in underwater networks.
- **Spatial Correlation:** While the readings from terrestrial sensors are often correlated, this is more unlikely to happen in underwater networks due to the higher distance among sensors.
- **Power**: Higher power is needed in underwater communications due to higher distances and to more complex signal processing at the receivers.

In this survey, we discuss several fundamental key aspects of underwater acoustic communications. We discuss the communication architecture of underwater sensor networks as well as the factors that influence underwater network design. The ultimate objective of this paper is to encourage research efforts to lay down fundamental basis for the development of new advanced communication techniques for efficient underwater communication and networking for enhanced ocean monitoring and exploration applications.

## II. UNDERWATER ACOUSTIC SENSOR NETWORKS

In this section, we describe the communication architecture of Underwater acoustic sensor networks. The reference architectures described in this section are used as a basis for discussion of the challenges associated with underwater acoustic sensor networks. The underwater sensor network topology is an open research issue in itself that needs further analytical and simulative investigation from the research community. In the remainder of this section, we discuss the following architectures:

- **Static two-dimensional** UW-ASNs for ocean bottom monitoring. These are constituted by sensor nodes that are anchored to the bottom of the ocean. Typical applications may be environmental monitoring, or monitoring of underwater plates in tectonics [4].
- **Static three-dimensional** UW-ASNs for ocean column monitoring. These include networks of sensors whose depth can be controlled by means of techniques discussed in Section II-B, and may be used for surveillance applications or monitoring of ocean phenomena (ocean biogeo-chemical processes, water streams, pollution, etc).

### A. Two-dimensional Underwater Sensor Networks

A reference architecture for two-dimensional underwater networks is shown in Fig. 1. A group of sensor nodes are anchored to the bottom of the ocean with deep ocean anchors. By means of wireless acoustic links, underwater sensor nodes are interconnected to one or more underwater sinks (uw-sinks), which are network devices in charge of relaying data from the ocean bottom network to a surface station. To achieve this objective, uw-sinks are equipped with two acoustic transceivers, namely a vertical and a horizontal transceiver. The horizontal transceiver is used by the uw-sink to communicate with the sensor nodes in order to: i) send commands and configuration data to the sensors (uw-sink to sensors); ii) collect monitored data (sensors to uw-sink). The vertical link is used by the uwsinks to relay data to a surface station. transmitter to communicate with the onshore sink (os-sink) or to a surface sink (s-sink).

Sensors can be connected to uw-sinks via direct links or through multi-hop paths. In the former case, each sensor directly sends the gathered data to the selected uw-sink. This is the simplest way to network sensors, but it may not be the most energy efficient, since the sink may be far from the node and the power necessary to transmit may decay with powers greater than two of the distance. Furthermore, direct links are very likely to reduce the network throughput because of increased acoustic interference due to high transmission power. In case of multi-hop paths, as in terrestrial sensor networks [5], the data produced by a source sensor is relayed by intermediate sensors until it reaches the uw-sink. This results in energy savings and increased network capacity but increases the complexity of the routing functionality as well. In fact, every network device usually takes part in a collaborative process whose objective is to diffuse topology information such that efficient and loop free routing decisions can be made at each intermediate node. This process involves signaling and computation.

Since, as discussed above, energy and capacity are precious resources in underwater environments, in UWASNs the objective is to deliver event features by exploiting multi-hop paths and minimizing the signaling overhead necessary to construct underwater paths at the same time. Vertical transceivers must be long range transceivers for deep water applications as the ocean can be as deep as 10 km. The surface station is equipped with an acoustic transceiver that is able to handle multiple parallel communications with the deployed uw-sinks. It is also endowed with a long range RF and/or satellite

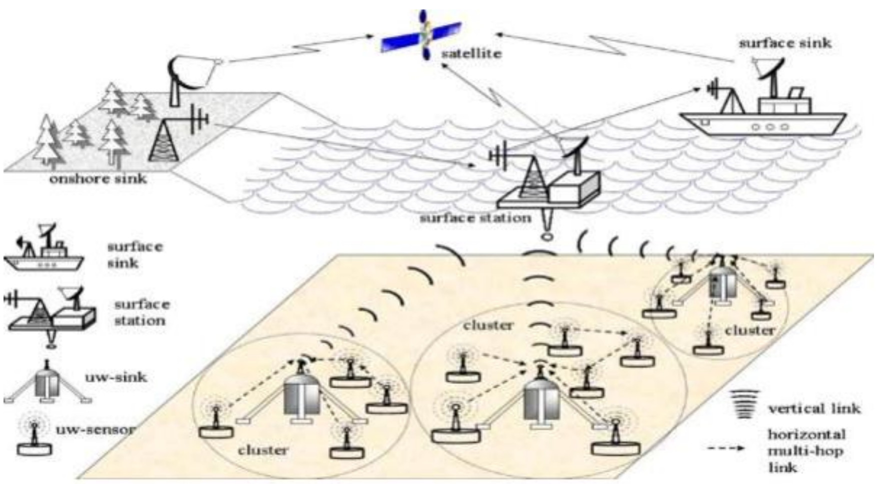


**Fig. 1. Architecture for 2D Underwater Sensor Networks.**

### B. Three-dimensional Underwater Sensor Networks

Three dimensional underwater networks are used to detect and observe phenomena that cannot be adequately observed by means of ocean bottom sensor nodes, i.e., to perform cooperative sampling of the 3D ocean environment. In three dimensional underwater networks, sensor nodes float at different depths in order to observe a given phenomenon. One possible solution would be to attach each uw-sensor node to a surface buoy, by means of wires whose length can be regulated so as to adjust the depth of each sensor node. However, although this solution allows easy and quick deployment of the sensor network, multiple floating buoys may obstruct ships navigating on the surface, or they can be easily detected and deactivated by enemies in military settings.

For these reasons, a different approach can be to anchor sensor devices to the bottom of the ocean. In this architecture, depicted in Fig. 2, each sensor is anchored to the ocean bottom and equipped with a floating buoy that can be inflated by a pump. The buoy pushes the sensor towards the ocean surface. The depth of the sensor can then be regulated by adjusting the length of the wire that connects the sensor to the anchor, by means of an electronically controlled engine that resides on the sensor.

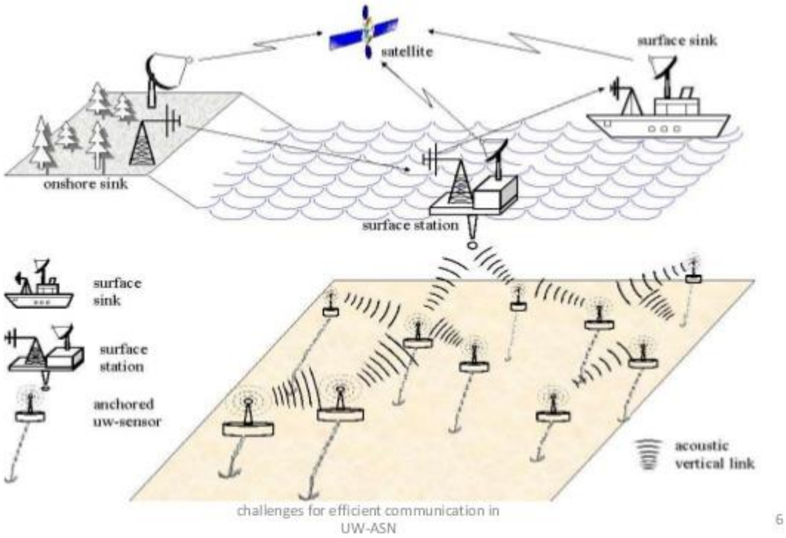


**Fig. 2. Architecture for 3D Underwater Sensor Networks**

Many challenges arise with such an architecture, that need to be solved in order to enable 3D monitoring, including:

- **Sensing coverage:**
  Sensors should collaboratively regulate their depth in order to achieve full column coverage, according to their sensing ranges. Hence, it must be possible to obtain sampling of the desired phenomenon at all depths.
- **Communication coverage:**
  Since in 3D underwater networks there is no notion of uw-sink, sensors should be able to relay information to the surface station via multihop paths. Thus, network devices should coordinate their depths such a way that the network topology is always connected, i.e., at least one path from every sensor to the surface station always exists.

## III. BASICS OF ACOUSTIC COMMUNICATION

Underwater acoustic communications are mainly influenced by path loss, noise, multi-path, Doppler spread, and high and variable propagation delay. All these factors determine the temporal and spatial variability of the acoustic channel, and make the available bandwidth of the UnderWater Acoustic (UW-A) channel limited and dramatically dependent on both range and frequency. Long-range systems that operate over several tens of kilometers may have a bandwidth of only a few kHz, while a short-range system operating over several tens of meters may have more than a hundred kHz bandwidth. In both cases these factors lead to low bit rates [6]. Moreover, the communication range is dramatically reduced as compared to the terrestrial radio channel. Underwater acoustic communication links can be classified according to their range as very long, long, medium, short, and very short links [1].

Acoustic links are also roughly classified as vertical and horizontal, according to the direction of the sound ray. As shown after, their propagation characteristics differ consistently, especially with respect to time dispersion, multi-path spreads, and delay variance. In the following, as usually done in oceanic literature, shallow water refers to water with depth lower than 100m, while deep water is used for deeper oceans. In the following we analyze the factors that influence acoustic communications in order to state the challenges posed by the underwater channels for underwater sensor networking. These include:

**Path loss:**

- **Attenuation:** Is mainly provoked by absorption due to conversion of acoustic energy into heat, which increases with distance and frequency. It is also caused by scattering and reverberation (on rough ocean surface and bottom), refraction, and dispersion (due to the displacement of the reflection point caused by wind on the surface). Water depth plays a key role in determining the attenuation.
- **Geometric Spreading:** This refers to the spreading of sound energy as a result of the expansion of the wave fronts. It increases with the propagation distance and is independent of frequency. There are two common kinds of geometric spreading: spherical (omni-directional point source), and cylindrical (horizontal radiation only).

**Noise:**

- **Man made noise:** This is mainly caused by machinery noise (pumps, reduction gears, power plants, etc.), and shipping activity (hull fouling, animal life on hull, cavitation).

- **Ambient Noise:** Is related to hydrodynamics (movement of water including tides, currents, storms, wind, rain, etc.), seismic and biological phenomena.

**Multi-path:**

- Multi-path propagation may be responsible for severe degradation of the acoustic communication signal, since it generates Inter-Symbol Interference (ISI).
- The multi-path geometry depends on the link configuration. Vertical channels are characterized by little time dispersion, whereas horizontal channels may have extremely long multi-path spreads, whose value depend on the water depth.

**High delay and delay variance:**

- The propagation speed in the UW-A channel is five orders of magnitude lower than in the radio channel. This large propagation delay (0.67 s/km) can reduce the throughput of the system considerably.
- The very high delay variance is even more harmful for efficient protocol design, as it prevents from accurately estimating the round trip time (RTT), key measure for many common communication protocols.

**Doppler spread:**

- The Doppler frequency spread can be significant in UWA channels [1], causing a degradation in the performance of digital communications: transmissions at a high data rate cause many adjacent symbols to interfere at the receiver, requiring sophisticated signal processing to deal with the generated ISI.

Most of the described factors are caused by the chemical physical properties of the water medium such as temperature, salinity and density, and by their spatio-temporal variations. These variations, together with the wave guide nature of the channel, cause the acoustic channel to be temporally and spatially variable. In particular, the horizontal channel is by far more rapidly varying than the vertical channel, in both deep and shallow water.

## IV. INTERNAL ARCHITECTURE OF UNDERWATER SENSOR

The internal architecture of underwater sensor is shown in figure 3. In internal architecture the CPU-on board controller, sensor interface HW, acoustic modem, memory, power supply and sensor are the principle parts in an underwater or acoustic wireless sensor network. These parts are mostly found in each such application of an acoustic wireless sensor network and constitute the main body.

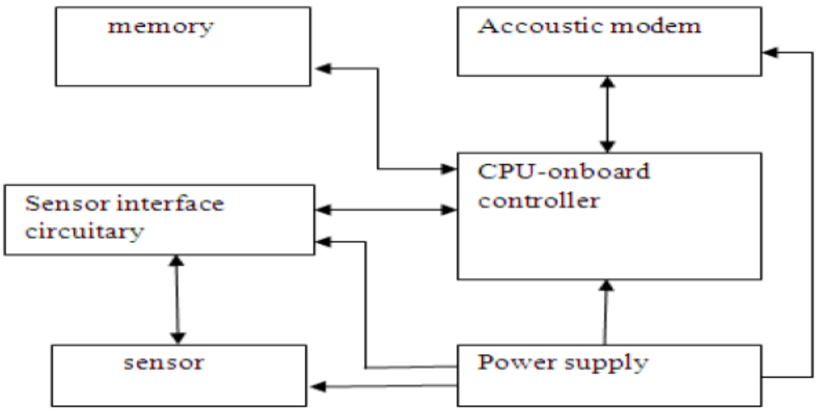


**Fig 3. Internal Architecture of Underwater Sensor**

It consists of the main controller that is interfaced with sensor through a sensor interface circuitry. The CPU or controller get the information from the sensor and put it in the memory, process it and send to another sensor through the acoustic modem. Sometimes all the sensor component are protected by the Bottom mounted instrument frames that are design to permit azimuthally omnidirectional communications, and protect the sensor and modem from potential impact of trawling gear[3].

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## V. APPLICATIONS

The above described features enable a broad range of applications for underwater acoustic sensor networks:

**A. Fastest way for finding underwater information:**

Underwater sensor is Now the most recent and speediest method for discovering data in light of its need and significance in a few circumstances i.e catastrophes, marines and so on which is useful for both the people additionally for scientists [3].

**B. Disaster Prevention :**

The Most important is disaster prevention characteristics of UWSN system able to perform seismic activity which produce tsunami warnings [3].

**C. Ocean Sampling Networks:**

It brings refined new automated vehicles i.e robots with advanced ocean sea models to enhance our capacity to watch and predict the ocean future conditions. We can organized the sensor in various depth in ocean.so we can sense the sea region at various depths [3]

**D. Environmental Monitoring :**

Environment Monitoring is a standout amongst the most essential use of UWSN. They sense the characteristics and properties of any object which include pollution monitoring, Water quality and habitant monitoring also.

**E. Mine Reconnaissance :**

The simultaneous operation of multiple AUVs (Autonomous underwater vehicle) a robot with acoustic sensor can be used to perform rapid environmental and detect mine like object [1].

**F. Pollution**

Monitoring and other environmental monitoring (chemical, biological, etc.).

**G. Distributed Tactical Surveillance.**

AUVs and fixed underwater sensors can collaboratively monitor areas for surveillance, reconnaissance, targeting and intrusion detection systems.

## VI. CHALLENGES

Major challenges in the design of Underwater Acoustic Networks are:

- **More costly devices:** Underwater sensor devices are more costly.
- **Hardware Protection requirement:** The uAs the devices are expensive so its require to protect against water damage
- **Need High Energy for communication:** In underwater sensor communication require more power because the data transfer will done in water medium. It is hard to propagate the signals easily which needs lots of energy and bandwidth.
- **Propagation delay:** The propagation delay is major problem in UWSN Because of water resistance
- **Limited battery power:** Battery power is limited and usually batteries can not be recharged, also because solar energy cannot be exploited. UWSNs suffer from a sensor's fouling and corrosion. Electronics component the battery, tend to degrade faster under extremely low temperatures such as the one found in deep underwater.
- **Bandwidth size limitation:** In the underwater sensor network bandwidth is another big problem. Because bandwidth size is limited.

## VII. CONCLUSION

In this paper, we overviewed the main challenges for efficient communications in underwater acoustic sensor networks. We outlined the peculiarities of the underwater channel with particular reference to networking solutions for monitoring applications of the ocean environment. The ultimate objective of this paper is to encourage research efforts to lay down fundamental basis for the development of new advanced communication techniques for efficient underwater communication and networking for enhanced ocean monitoring and exploration applications.

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