# Underwater Sensor Network

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**ABSTRACT**

As electromagnetic waves do not propagate well underwater, acoustics plays a key role in underwater communication. Due to significant differences in the characteristics of electromagnetic and acoustic channels, networking protocols for underwater systems differ from those developed for wired and wireless radio networks.

This paper explores applications and challenges for Underwater sensor networks. Underwater sensor nodes will find applications in oceanographic data collection, pollution monitoring, offshore, exploration, disaster prevention, assisted navigation and tactical surveillance applications. We study the localization problem in large-scale underwater sensor networks.

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 characteristics of the underwater channel are detailed.

We study the localization problem in large-scale underwater sensor networks.

Underwater networks consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area.

We have also discussed here the underwater network architecture with five-layer model.

## 1. INTRODUCTION

### 1. 1. System architecture

The UNA takes into account underwater networking needs and is specific enough to allow easy integration between implementations of different layers by different research groups. At the same time, the architecture is flexible enough to accommodate different application requirements and new ideas. In addition to defining a layered architecture, the architecture definition specifies the primitives that define communication between layers.

Additionally, a UNA Framework Application Programming Interface (FAPI) is defined to enable layer implementations to be easily incorporated into various stacks. To ensure flexibility, the architecture also defines an extension framework so that the architecture can be expanded and cross-layer optimization can be taken into account.

The UNA is based on a five-layer model. Each of the nodes consists of the layers shown in Fig. 1. The application layer is not defined in the UNA specifications, but is rather a client of the four layers (transport, network, data link and physical) defined in the UNA. The UNA does not define the algorithms used in each of the four layers. It only defines the service access point interface (SAPI) to be implemented by each of the layers.

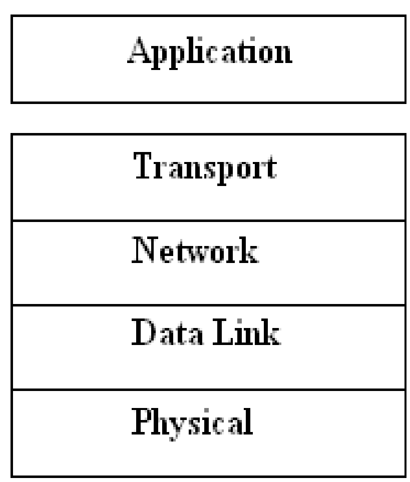


Fig. 1. Layers in the UNA

As typical underwater systems have limited processing capability, the protocol has been kept as simple as possible without significantly compromising performance. The UNA specifications currently do not include any recommendations for authentication and encryption. These may be easily implemented at the application layer or via a spreading scheme at the physical layer. The UNA will be expanded later to explicitly address these requirements.

Each layer is described by a SAPI. The SAPI is defined in terms of messages being passed to and from the layer. The clients (usually higher layers) of a layer invoke the layer via a request (REQ). The layer responds to each REQ by a response (RSP). Errors are reported via an ERR RSP with error codes. If the layer needs to send unsolicited messages to the client, it does so via a notification (NTF). A layer communicates logically with its peer layer via protocol data units (PDU). As the peer-to-peer communication is symmetric, a layer may send a REQ PDU to its peer layer at any time. It would optionally respond to such a PDU with a RSP PDU. This is logically depicted in Fig. 2.

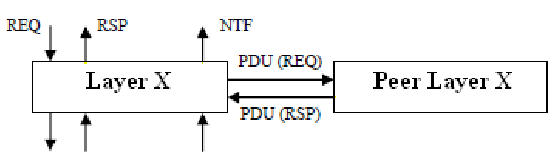


Fig. 2. Message Nomenclature in the UNA

*Transport Layer* The transport layer specifications support two modes of communications – connection oriented and datagram. A connection oriented mode allows for persistent reliable connection with the open, write and close primitives and incoming data notifications. The datagram mode allows for reliable or unreliable delivery of datagram's via send primitives and incoming datagram notifications.

*Network Layer* The network layer provides routing capability to the protocol stack. It provides an unreliable packet delivery service over the routes. However, the layer may optionally implement some degree of reliability via retransmits. If the layer knows that a packet could not be delivered due to a lack of available route, it may inform the client layer via the no route notification.

*Data Link Layer* The data link layer provides single hop data transmission capability; it will not be able to transmit a packet successfully if the destination node is not directly accessible from the source node. It may include some degree of reliability. It may also provide error detection capability (e.g. CRC check).

*Physical Layer* The physical layer provides framing, modulation and error correction capability (via FEC). It provides primitives for sending and receiving packets. It may also provide additional functionality such as parameter settings, parameter recommendation, carrier sensing, etc.

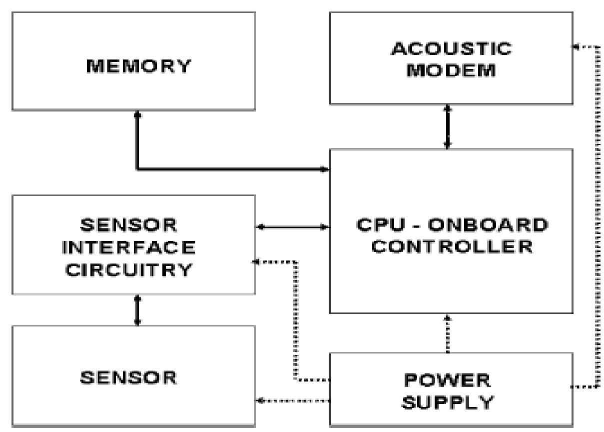


Fig. 3. Internal architecture of an underwater sensor node.

The typical internal architecture of an underwater sensor is shown in Fig. 3.
It consists of a main controller/CPU which is interfaced with an oceanographic instrument or sensor through a sensor interface circuitry. The controller receives data from the sensor and it can store it in the onboard memory, process it, and send it to other network devices by controlling the acoustic modem. The electronics are usually mounted on a frame which is protected by PVC housing. Sometimes all sensor components are protected by bottom-mounted instrument frames that are designed to permit azimuthally omnidirectional acoustic communications, and protect sensors and modems

from potential impact of trawling gear, especially in areas subjected to fishing activities. In [3], the protecting frame is designed so as to deflect trawling gear on impact, by housing all components beneath a low-profile pyramidal frame.

### 1.2. Communication Architecture

In this section, we describe the communication architecture of underwater acoustic sensor networks. In particular, we introduce reference architectures for two dimensional and three dimensional underwater networks, and present several types of autonomous underwater vehicles (AUVs) which can enhance the capabilities of underwater sensor networks.
The communication architectures introduced here are used as a basis for discussion of the challenges associated with underwater acoustic sensor networks.

*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 [8].

*Static three-dimensional UW-ASNs* for ocean column monitoring. These include networks of sensors whose depth can be and may be used for surveillance applications or monitoring of ocean phenomena.

*Three-dimensional networks* of autonomous underwater vehicles (AUVs). These networks include fixed portions composed of anchored sensors and mobile portions constituted by autonomous vehicles.

#### 1.2.1. Two-dimensional underwater sensor networks

A reference architecture for two-dimensional underwater networks is shown in Fig. 4. A group of sensor nodes are anchored to the bottom of the ocean with deep ocean anchors. Underwater sensor nodes are interconnected to one or more underwater sinks (uw-sinks) by means of wireless acoustic links.
Uw-sinks, as shown in Fig. 4, 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 260 I.F.

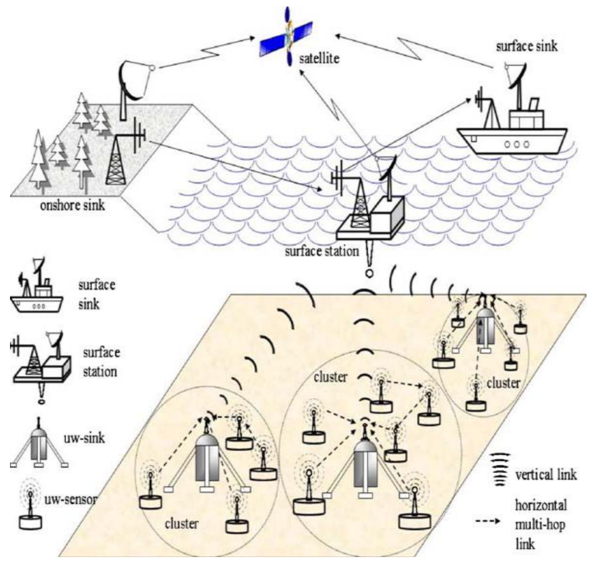


Fig. 4. Architecture for 2D underwater sensor networks.

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 uw-sinks to relay data to a surface station. In deep water applications, vertical transceivers must be long range transceivers 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 uwsinks. It is also endowed with a long range RF and/or satellite transmitter to communicate with the onshore sink (os-sink) and/or to a surface sink (s-sink).
Sensors can be connected to uw-sinks via direct links or through multi-hop paths. In case of multi-hop paths, as in terrestrial sensor networks [6], the data produced by a source sensor is relayed by intermediate sensors until it reaches the uw-sink. This may result in energy savings and increased network capacity, but increases the complexity of the routing functionality.

### 1.2.2. 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.

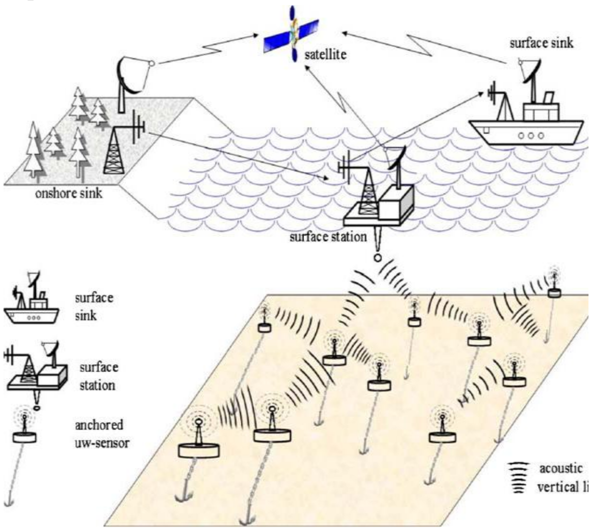


Fig. 5. Architecture for 3D underwater sensor networks.

In this architecture, depicted in Fig. 5, 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. A challenge to be addressed in such an architecture is the effect of ocean currents on the described mechanism to regulate the depth of the sensors.

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 3D coverage of the ocean column, according to their sensingranges. Hence, it must be possible to obtain sampling of the desired phenomenon at all depths.

• Communication coverage. Since in 3D underwater networks there may be no notion of uw-sink, sensors should be able to relay information to the surface station via multi-hop paths. Thus, network devices should coordinate their depths in 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.

## 2. APPLICATIONS

We see our approaches as applicable to a number of applications, including seismic monitoring, equipment monitoring and leak detection, and support for swarms underwater robots. We review the different characteristics of each of these below.

**Seismic monitoring**: A promising application for underwater sensor networks is seismic monitoring for oil extraction from underwater fields. Frequent seismic monitoring is of importance in oil extraction; studies of variation in the reservoir over time are called .4-D seismic. and are useful for judging field performance and motivating intervention. Terrestrial oil fields can be frequently monitored, with fields typically being surveyed annually, or quarterly in some fields, and even daily or continuously. in some gas storage facilities and permanently instrumented fields.

**Equipment Monitoring and Control**: Underwater equipment monitoring is a second example application. Ideally, underwater equipment will include monitoring support when it is deployed, possibly associated with tethered power and communications, thus our approaches are not necessary. However, temporary monitoring would benefit from low-power, wireless communication. Temporary monitoring is most useful when equipment is First deployed, to confirm successful deployment during initial operation, or when problems are detected.

**Flocks of Underwater Robots**: A third and very different application is supporting groups of underwater autonomous robots. Applications include coordinating adaptive sensing of chemical leaks or biological phenomena (for example, oil leaks or phytoplankton concentrations), and also equipment monitoring applications as described above.

## 3. CHALLENGES

Localization in large-scale UWSNs is largely unexplored. The adverse aqueous environment, the node mobility and the network scale pose huge challenges.

**Range-free Localization Schemes**: Since radio does not work well in water, UWSN has to employ acoustic communications. Due to its unique features of large latency, low bandwidth and high error rate, the underwater acoustic channel poses many constraints on localization schemes. Traditional range-free localization schemes which adopt message flooding [4, 9] are inefficient because of their huge communication overhead.

**Range-based Localization Schemes :**

Range-based localization schemes have potentials for UWSNs since acoustic signals can help to significantly improve the accuracy of range estimates. In general, range-based localization schemes can be further divided into two categories: centralized and distributed.

Centralized localization schemes usually need a global central node or several local centers to collect all the needed information from other nodes. Then these central nodes use some optimization methods to estimate the node locations based on the available information. It is evident that centralized localization schemes are not good candidates for large-scale UWSNs since they will introduce relatively large communication overhead and cannot respond timely to node location changes.

Distributed range-based localization schemes these schemes are proposed for two dimensional terrestrial sensor networks and cannot be directly applied into three dimensional UWSNs. For three dimensional underwater sensor networks, however, this method is not applicable, because the rigidity theory for three or more dimensional graph has not been well established.

**Small-scale Underwater Localization Systems:**

Common GPS cannot work in the underwater environment. In order to get the absolute location information for the underwater objects, "underwater GPS" systems, such as GIB (GPS Intelligent Buoys) [2] and PARADIGM [10], have been proposed. Normally, these underwater GPS systems depend on the buoys on the surface to provide absolute position information and these buoys act as the satellites of the common GPS.

For large-scale underwater sensor networks, we cannot assume that all of these sensor nodes can get their absolute positions from the underwater GPS systems for the following two reasons. First, this needs all sensors to be equipped with some costly hardware, which may not be feasible in practice. Second, the surface buoys need to guarantee that all sensors can receive their messages.

## 4. HARDWARE FOR UNDERWATER ACOUSTIC COMMUNICATIONS

Underwater Acoustic Networks, including but not limited to, Underwater Acoustic Sensor Networks (UASNs) [5] are defined as networks composed of more than two nodes, using acoustic signals to communicate, for the purpose of underwater applications. Acoustic communications is a very promising method of wireless communication underwater. At the hardware level, underwater acoustic communication differs from in-the-air RF in a few key ways. In both systems we transmit a tone or carrier, which carries the data through modulation, such as amplitude, frequency or phase modulation. The primary differences between modulation techniques lies in the complexity of the receiver, the bandwidth required, and the minimum acceptable received signal-to-noise ratio (SNR). SNR is usually expressed as Eb=No or energy per bit over noise spectral density [7], [1]. As an example, binary frequency shift keying (FSK), requires about 14 dB Eb=No for a $1*10^{-6}$ BER.

The received SNR depends on a few basic factors:

**Transmit Power**: There is no fundamental limit to Transmitter power, but it can have a major effect on the energy budget for the system. For energy efficiency and to minimize interference with neighboring transmitters we wish to use the smallest possible transmitter power.

**Data Rate**: This is a tradeoff between available power and channel bandwidth. Because acoustic communications are possible only over fairly limited bandwidths, we expect a fairly low data rate by comparison to most radios. We see a rate of currently 5kb/s and perhaps up to 20kb/s. In application such as robotic control, the ability to communicate at all (even at a low rate) is much more important than the ability to send large amounts of data quickly.

**Noise Level**: Noise levels in the ocean have a critical effect on sonar performance. We are interested in the frequency range between 200 Hz and 50 kHz (the mid frequency band). In this frequency range the dominant noise source is wind acting on the sea surface. Knudsen [9] has shown a correlation between ambient noise and wind force or sea state. Ambient noise increases about 5dB as the wind strength doubles. Peak wind noise occurs around 500 Hz, and then decreases about -6dB per octave. At a frequency of 10,000 Hz the ambient noise spectral density is expected to range between 28 dB/Hz and 50 dB/Hz relative to 1 micro Pascal. This suggests the need for wide range control of transmitter power.

**Signal Attenuation**: Attenuation is due to a variety of factors. Both radio waves and acoustic waves experience 1=R2 attenuation due to spherical spreading. There are also absorptive losses caused by the transmission media. Unlike in-the-air RF, absorptive losses in underwater acoustics are significant, and very dependent on frequency. At 12.5 kHz absorption it is 1dB/km or less. At 70 kHz it can exceed 20dB/km. This places a practical upper limit on our carrier frequency at about 100 kHz. There are additional loss effects, mostly associated with scattering, refraction and reflections. A major difference between RF and acoustic propagation is the velocity of propagation. Radio waves travel at the speed of light. The speed of sound in water is around 1500 m/s, and it varies significantly with temperature, density and salinity, causing acoustic waves to travel on curved paths. This can create silent zones where the transmitter is inaudible. There are also losses caused by multipath reflections from the surface, obstacles, the bottom, and temperature variations in the water and scattering from reflections off a potentially rough ocean surface.

**Proposed Acoustic Communications Design**: Many of these forms of loss are unique to acoustic communications at longer distances. In particular, multipath reflections, temperature variation, and surface scattering are all exaggerated by distance. Inspired by the benefits of short range RF communication in sensor networks, we seek to exploit short-range underwater acoustics where our only significant losses are spreading and absorption. We are developing a multi-hop acoustic network targeting communication distances of 50-500 meters. Using a simple FSK signaling scheme we anticipate sending 5kb/s over a range of 500m using a 30 m transmitter output. The primary limitation is set by spreading loss and the background noise of the ocean.

## 5. LOCALIZATION FOR LARGE-SCALE UWSNS

Each non-localized node maintains a counter, n, of localized messages it broadcasts. We set a threshold N (referred to as “localization message threshold”) to limit the maximum number of localization messages each node can send. In other words, N is used to control the localization overhead. Besides, each non-localized node also keeps a counter, m, of the reference nodes to which it knows the distances. Once the localization process starts, each non-localized node keeps checking m.

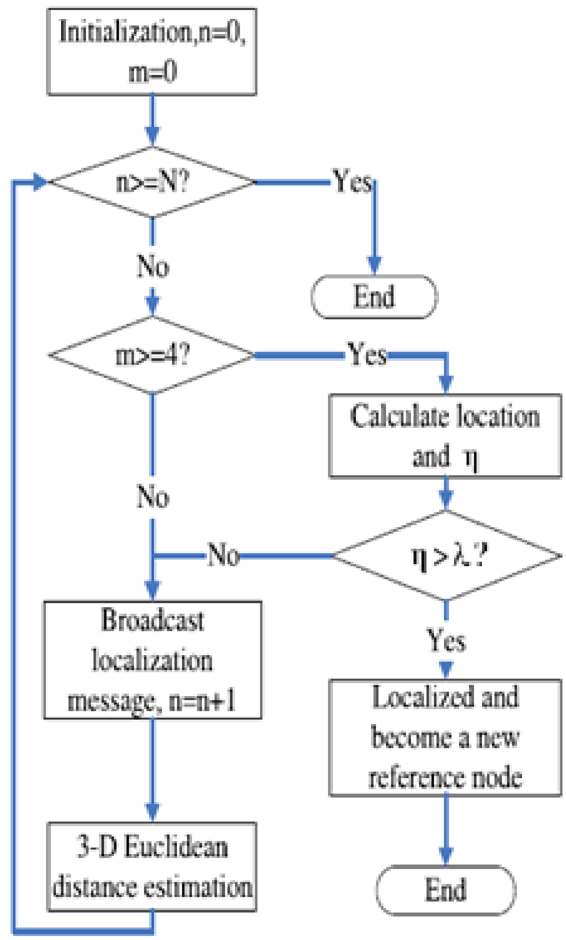


Fig. Ordinary node localization process

There are two cases:

(1) m < 4. This non-localized node broadcast a localization message which contains all its received reference nodes' locations and its estimated distances to these nodes. Its measured distances to all one-hop neighbors are also included in this localization message. Besides, this node uses the 3-dimensional Euclidean distance estimation approach to estimate its distances to more non-neighboring reference nodes. After this step, the set of its known reference nodes is updated. Correspondingly, m is updated and the node returns to the m-checking procedure.

(2) m >= 4. This non-localized node selects 4 reference nodes with the highest confidence values for location estimation. After it gets its location, it computes confidence value $\eta$. If $\eta$ is larger than or equal to the confidence threshold $\gimel$, then it is localized and labels itself as a new reference node. Otherwise, if $\eta$ is smaller than $\gimel$, the node will take the same actions as described in case (1). The complete localization procedure of an ordinary node is illustrated in above Fig.

## 6. CONCLUSION

We have outlined the UNA specifications in this paper. The primary aim of the specifications is to define a common framework that the underwater networking community may use. This would allow implementations of layers from different sources to interoperate and improve the pace of advances in the field. This paper has summarized our ongoing research in underwater sensor networks, including potential applications and research challenges.

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