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# Self-deployment of mobile underwater acoustic sensor networks for maximized coverage and guaranteed connectivity

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ABSTRACT

Self-deployment of sensors with maximized coverage in Underwater Acoustic Sensor Networks (UWASNs) is challenging due to difficulty of access to 3-D underwater environments. The problem is further compounded if the connectivity of the final network is desired. One possible approach to this problem is to drop the sensors on the water surface and then move them to certain depths in the water to maximize the 3-D coverage while maintaining the initial connectivity. In this paper, we propose a fully distributed node deployment scheme for UWASNs which only requires random dropping of sensors on the water surface. The idea is based on determining the connected dominating set (CDS) of the initial network on the surface and then adjust the depths of all neighbors of a particular dominator node (i.e., the backbone of the network) for minimizing the coverage overlaps among them while still keeping the connectivity with the dominator. The process starts with a leader node and spans all the dominators in the network for repositioning them. In addition to depth adjustment, we studied the effects of possible topology alterations due to water mobility caused by several factors such as waves, winds, currents, vortices or random surface effects, on network coverage and connectivity performance. On the one hand the mobility of nodes may help the topology to get stretched in 2-D, which helps to maximize the coverage in 3-D. On the other hand the mobility may cause the network to get partitioned where some of the nodes are disconnected from the rest of the topology. We investigated the best node deployment time where 2-D coverage is maximized and the network is still connected. To simulate the mobility of the sensors, we implemented meandering current mobility model which is one of the existing mobility models for UWASNs that fits our needs. The performance of the proposed approach is validated through simulation. Simulations results indicate that connectivity can be guaranteed regardless of the transmission and sensing range ratio with a coverage very close to a coverage-aware deployment approach.



## 1. Introduction

Underwater Acoustic Sensor Networks (UWASNs) consist of a large number of sensors on and underwater which can communicate via acoustic links [1,2]. Similar to terrestrial wireless sensor networks (WSNs), these networks

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provide numerous advantages in terms of coverage quality, labor, cost and deployment as opposed to traditional monitoring tools. Within the last decade, a lot of studies focused on the issues related to communication underwater given that radio frequency (RF) signals do not travel underwater. The design of an acoustic modem, modeling of the channel, medium access, routing and sensing issues had been the main focus of researchers [3,4].

Node deployment and mobility modeling have been other issues studied in UWASNs given that underwater is not readily accessible and sensors can drift due to the characteristics of the environment. The main goals in these studies were to reduce the cost and time of deployment with desired objectives in terms of coverage, accuracy and communication quality [5,6]. The deployment is a crucial issue especially for the applications which require rapid and remote deployment. For instance, deployment of a UWASN for measuring the water quality of a lake or river which is believed to be contaminated requires rapid deployment to measure the water quality and inform the public. Another example would be the deployment of a UWASN in a remote ocean location for environmental or habitat monitoring which is not easily accessible.

For such cases, there needs to be a mechanism to remotely deploy sensors at a reasonably short time. Since manual deployment is out of question due to accessibility and time constraints, one possibility would be to randomly drop sensors on the water surface from an aerial vehicle and then expand them to 3-D with depth adjustment. This requires the ability of the sensors to adjust their depths in the water via a mechanism which can change the weight of the sensor using air or water such as the one described in [7]. The vertical movement of acoustic sensors resembles self-spreading of sensors in 2-D environments when they have the ability of moving. While there has been studies leveraging this capability of acoustic sensors to expand their coverage [5,6], none of them can guarantee connectivity of the stretched network with a surface station so that all the collected data can be relayed to an on-shore station. To the best of our knowledge, self depth adjustment of sensors subject to connectivity constraint is a novel problem that has not been studied in the past. Connectivity introduces new challenges since a path from every sensor to the surface station needs to be guaranteed. This requires a controlled strategy maintained by the surface sink so that network connectivity is maintained. In a distributed context, this requires messaging among the sensors. In addition, the coverage can still be extended within the limits of connectivity. For this issue, we assume a spherical sensing coverage that exists with the ultrasonic sensors.

In this paper, we propose a novel autonomous deployment scheme for underwater ultrasonic sensors which can maximize the coverage in 3-D while guaranteeing the connectivity among the sensors and a surface sink node to collect data. Our scheme assumes an initially randomly deployed and connected UWASN on the surface of the water in 2-D. This can be achieved by randomly dropping a certain number of sensors in a targeted area [8]. The scheme then determines the connected dominating set (CDS) (i.e., a network backbone) of the whole UWASN at 2-D plane. The main goal here is to determine a backbone of the network consisting of nodes called *dominators* and then maintain the network connectivity underwater by keeping the network backbone connected (i.e. keeping only CDS edges). Two connected dominators can still maintain their connectivity while being stretched along the $z$-axis as much as possible in order to provide minimal sensing coverage overlapping until they stay in each other's communication range. This idea is then applied to every dominator along with its dominator and dominatee (i.e., non-dominator) neighbors one by one. The approach is named as CDS-based Depth Computation Approach (CDA). The CDA algorithm runs on the dominator nodes in a turn-based manner.

To improve the coverage of the final 3-D network, we also exploit the mobility of the sensors. It is well-known that free-floating sensors on the water surface are subject to mobility due to several factors such as waves, winds, sub-surface currents, vortices or random surface effects. Such mobility on the water surface causes that the nodes move away from each other and thus the network topology alters gradually. In this paper, we study the effects of dynamic topology alteration due to mobility on network coverage and connectivity. Our goal is to utilize the network expansion in 2-D to improve the 3-D coverage of the resultant topology produced by CDA. We simulated the displacement of the network topology under Meandering Current Mobility [9] (MCM) model and determined best deployment time where the 2-D coverage is maximized and the network in 2-D is still connected.

The proposed approach is validated through extensive simulations and has been shown to guarantee the connectivity while achieving a 3-D coverage that is very close a baseline approach targeted for maximized coverage. We also show that the resultant topology has desirable characteristics in terms of average node degree and expected path length which are crucial for fault-tolerance and data delay.

Our contributions in this paper can be summarized as follows:

- We propose an autonomous and efficient deployment scheme which guarantees connectivity of the sensors to the surface station while maximizing the coverage of the nodes.
- We adapt CDS idea from graph theory for maintaining connectivity among the nodes and the surface station.
- We determine the optimal time for the deployment time based on meandering mobility model in order to maximize coverage.

This paper is organized as follows. Next section summarizes the related work. Section 3 explains the preliminaries of the proposed scheme. In Section 4, we present the details of the proposed approach. Section 5 is dedicated to the effects of mobility model on network coverage and connectivity. Section 6 provides evaluation of the proposed approach. Finally, Section 7 concludes the paper.