

Deployment algorithms in Underwater Acoustic Wireless Sensor Networks: A Review

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Abstract: Deployment of sensors in the underwater acoustic sensor network is a very challenging task due to the complex 3d environment in underwater sensor networks because acoustic signal is affected by salinity, temperature, and pressure. The main objective of deployment algorithm is to achieve maximum coverage with a minimum number of underwater acoustic sensor nodes or surface gateways in underwater acoustic sensor networks. A network with complex deployment increases the complexity of the other operation on the network such as routing protocol, localization etc. in this paper we study the various deployment algorithms. According to the mobility of the nodes to be deployed in the network, classification of the algorithms is static nodedeployment, self-adjusting nodedeployment, and movement aware node deployment.

Index Terms: Underwater acoustic sensor networks, sensing coverage, sensor nodes, deployment, surface gateway, and underwater sink nodes.

1. Introduction

Underwater Acoustic Sensor Networks (UASNs) includes sensors and vehicles which are connected to each other to perform a specific monitoring task for a given area [1]. Some application of underwater acoustic networks are ocean sampling, pollution monitoring, detecting underwater oilfields, natural disaster prevention, assisted navigation, distributed tactical surveillance, mine detection etc. [2]. Design of underwater acoustic sensor network is a very challenging task Some of the Major challenges related to the design of underwater acoustic networks includes limited available bandwidth; the underwater channel is harshly impaired, especially due to multi-path and fading; very high and variable propagation delay in underwater as compared to terrestrial; extreme characteristics of underwater channel causes high bit error rates and temporary losses of connectivity; sensors have limited battery power and these batteries cannot be recharged underwater; underwater sensors are prone to failures.

Underwater networking is an unmapped area, although it was started by United States in 1945 during World War II. They developed an underwater telephone to

communicate with submarines underwater. The major difference between UASNs and terrestrial sensor network is the density of the sensor nodes in the interested area. In UASNs nodes are sparsely deployed. Another difference between Underwater WSNs and terrestrial WSNs is the different use of communication signals. The radio signal are limited to the short distances because of rapid attenuation while optical signals do not work well in advert conditions because of scattering [5]. The acoustic signals are used in UWSNs because of less attenuation and it can travel to relatively longer distance (i.e. approx. 1500 m/s) underwater.

The sensor nodes in the network communicate with each other. On the basis of communication underwater acoustic sensor networks are of two types: 2D underwater architecture and 3D underwater architecture. In two-dimensional underwater networks, a group of sensor nodes is deployed on the seabed. Sensor nodes are attached to one or more *underwater sinks* by means of wireless acoustic links. Uw-sinks collect data from the network and send it to the surface station. In three-dimensional underwater

networks architecture sensor nodes float at different depths. The sink nodes are either attached to the surface buoys through wires where the depth of sensor nodes can be adjusted by regulating the length of the wires or anchor them to the bottom of the ocean [3].

Deployment of sensors is a challenging task in underwater acoustic sensor network. The main challenges that arise with two-dimensional architecture are: (i) what should be the minimum number of sensors and underwater gateways that need to be deployed to achieve the maximum communication coverage (ii) what should be guidelines to choose the optimal deployment surface are; and (iii) what should be the number of redundant node to achieve the robustness of the sensor network in case of sensor node failure. There are some challenges in deployment in 3D UASNs including: (i) sensors should regularly change their depth to achieve 3D sensing coverage of the ocean column; (ii) sensors should have capability to send information to the surface station via multi-hop paths, the sensor nodes should self-adjust their depth in such a way that the network topology is always connected, i.e., at least one path always exist from every sensor to the surface station, and achieves communication coverage.

In this paper, we have studied different deployment algorithms and classify them into three categories namely: static node deployment, self-adjusting node deployment and movement aware deployment algorithms. The remainder of the paper is organized as follows: in section 2, we describe the classification of deployment algorithms for underwater acoustic sensor networks. In section 3, we review the static node deployment algorithm. In section 4, related works on self-adjusting node deployment algorithm. In section 5, we describe the movement-aware node deployment algorithms. In section 6, we draw the main conclusion.

2. Classification of Deployment Algorithms

Most of the deployment algorithms in WSNs are based on 2-Dimensional sensor network architecture. Underwater acoustic networks as they have 3-Dimensional architecture,

needs design improvement and increases computation complexity, the existing algorithms may no longer be operative in UASNs. All problems relate to the deployment of the sensor nodes cannot be solved by the extension of two-dimensional algorithms. For underwater networks, new algorithms should be specifically designed for 3D UASNs which can support the geometric properties of 3D UASNs.

On the basis of node mobility in [6], the deployment algorithms are classified into three categories: static node deployment, self-adjustment node deployment, and movement-aware node deployment as shown in Figure 1.

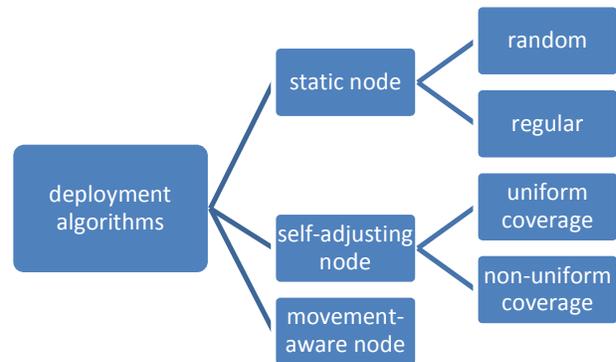


Figure 1: Classification of deployment algorithms for UASNs

- Static node deployment: Sensors are assumed to have a fixed location after initial deployment. They are either attached to surface buoys or anchored at the bottom of the ocean. Static sensor deployment is further classified into random deployment and regular deployment.
- Self-adjusting node deployment: sensor nodes adjust their locations to get the desired position in order to improve the coverage, once they are deployed. Self-adjusting node deployment algorithms are further classified as uniform coverage deployment and non-uniform coverage deployment.

- Movement-aware node deployment: the sensor nodes float with water current and continuously change their position underwater.

3. Static node deployment algorithm

Static sensor deployment algorithms are of two types' random static node deployment and regular static node deployment. Random deployment algorithms are applied where no specific deployment requirements are specified. Sensor's positions follow a particular distribution, defined by a Probability Density Function (PDF), depending on the deployment strategy [6]. Author has categorized the random deployment into simple and compound. In regular deployment, sensors are placed in a regular pattern such as the vertices of a polygons or polyhedrons, as the triangular-grid deployment, which is based on geometric properties [7]. Sensors are placed at vertices of the equilateral triangle to cover a two-dimensional rectangular area with a minimum number of sensors as shown in figure 2.

In [8] author has focused on the deployment of surface gateways to overcome the problem of high propagation delay. Multiple surface-level gateways (also called sink nodes) are deployed instead of single sink node. In the underwater sensor network, each sensor node monitors and detect events position near to its position and then sends these measurements to a surface gateway node (also called as a sink for the UWSN) through the network, which then transfer these information to the control station. Underwater sensor nodes can send the data packets to the control station via their nearest surface gateway. Surface gateway forward the packet to base station using electromagnetic waves, as electromagnetic wave propagates much faster than acoustic wave in water, surface gateways takes very less time to send packets to the control station with relatively small energy consumption. Integer Linear Programming (ILP) is used for solving deployment optimization problem.

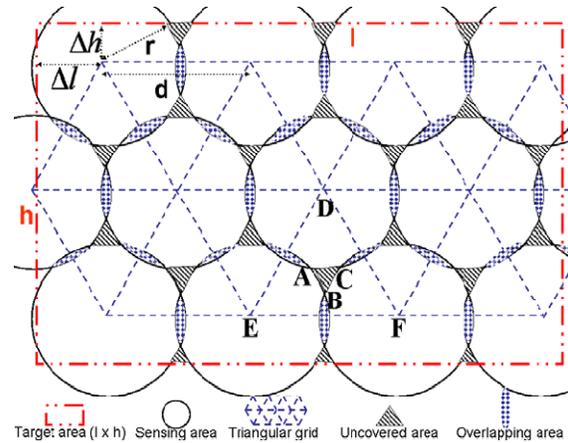


Figure 2: Triangular grid deployment

The deployment algorithm assumes that the sensor nodes are already deployed underwater wireless network, the problem is reduced to find the optimal deployment locations for a given number of surface gateways. Later, the surface gateway deployment optimization problem is solved using heuristic approaches [9]. The primary goal of the deployment is to get the maximum coverage with a minimum number of nodes to achieve this goal author [10] has aimed to develop a node deployment algorithm to achieve 100% coverage with a minimum number of nodes. To achieve their goal they used Kelvin's conjecture to justify that nodes placement in the middle of truncated octahedrons (as shown in the figure) cells, which are, created by Voronoi tessellation in 3D space. Locations of newly introduced nodes can be formulized in Integer Linear Programming (ILP), where the objective function is to find the location with minimize the transmission loss between the two nodes with a given number of sensors. The algorithm begins with finding a space-filling polyhedron which can best approximate the sensing sphere. For this, the ratio of the volume of the polyhedron to the volume of the communication sphere of radius r is used to measure the volumetric quotient. Among all other polyhedrons, It has been observed that Truncated Octahedron (TO) has the highest volumetric quotient among all other polyhedrons. A

TO contains 14 faces, 8 of which are hexagonal and 6 are square as shown in Figure 3.

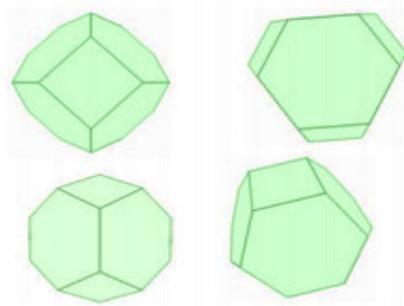


Figure 3: Truncated Octahedron

The length of the edge of the hexagonal and square face is a . The volume of a TO is $8\sqrt{2}a^3$ and the radius of its circumsphere is $\frac{\sqrt{10}a}{2}$. The volumetric quotient of TO can be calculated as follows:

$$8\sqrt{2}a^3 / \frac{4}{3}\pi \left(\frac{1}{2}\sqrt{10}a\right)^3 = 24/5\sqrt{5}\pi = 0.68329$$

The deployment algorithm then finds the locations of the RNs be placed to cover the space-filling polyhedron, i.e., TOs. The input of the algorithm is the radius R of the circumsphere of TO and the co-ordinates of a seed point, say (x, y, z) . The output of the algorithm gives the coordinates of the locations of RNs are to be placed. The coordinates of the RNs locations with an arbitrary seed-point (cx, cy, cz) can be calculated as follows:

$$\left(cx + (2u + w)\frac{2R}{\sqrt{5}}, cy + (2v + w)\frac{2R}{\sqrt{5}}, cz + w\frac{2R}{\sqrt{5}}\right)$$

In [12] a deployment algorithm (UDA) for underwater sensor networks is proposed to maximize the network lifetime. UDA partitions the space into layers composed of clusters while maintaining full coverage and full connectivity. A cluster head selected by all sensors in the cluster collect all sensed data in the cluster and forward it to

all neighbors in its communication range. Forwarding packets in addition, nodes closer to sinks are selected to perform a heavier data-relaying responsibility.

4. Self-adjusting node deployment algorithm

Sensors nodes can have the capability to change their position in order to increase coverage. In 3d underwater architecture sensors are attached to the surface buoys or at the sea bottom with wires. They can adjust their depth by regulating wire's length [14]. There are two kinds of self-adjusting sensor deployments: uniform and non-uniformed. In uniform deployment sensors are deployed uniformly in the given area and in non-uniform deployment of the sensor node's deployment depends on the environment so that it can cover the whole interested area with efficiency. A distributed node deployment scheme has proposed which is an iterative deployment algorithm; sensor nodes self-adjust their position during each iteration in order to increase the initial network coverage [15]. The underwater sensor nodes are deployed at bottom of the ocean in initial stage and have capability of move in only vertical direction, nodes relocate themselves in different depth so that they can reduce the sensing overlaps among the neighboring nodes. The rigid theory is introduced to define 'rigidity-coverage value of sensor domain' as the evaluation for the positions of underwater sensors in a 3D sensor network in [16]. Author has developed a moving strategy of underwater sensors to form a complete sensor self-organization deployment mechanism. Through this moving strategy, the optimal position of all sensors is achieved independently and periodically. To develop a more efficient network a periodically detect the coverage rate is needed so that sensors can be relocated at the uncovered area if any [17]. To maximize coverage author has developed two redeployment algorithms; one is based on adding new nodes to the existing while the other one is by moving redundant ones. Shadow zones in Underwater Wireless

Sensor Networks (UWSNs) affect the communication system performance.

To overcome the problem of shadow zone a reorganization scheme has proposed [18], In the case of shadow zone, the scheme is able to maintain connectivity in 3D- UWSNs. Shadow zone are areas where there is little propagating signal energy [19]. To achieve the goal instead of deploying single sensor two sensors are placed at one place. The sensors operate as a single sensor until shadow zone appears. In the case of shadow zone, one sensor remains at the same position and another sensor relocate itself. The sensors stay connected through wires in shadow zone to maintain robust communication. The new optimal position of the sensor is determined by non-linear programming problem. In [20] authors have presented a sensor deployment algorithm inspired by a group of fishes. In their work they used the behavior of fish swarm and taking the crowd factor into account, the method can motivate the sensors to cover almost all the events and make the sensors density match the events density occurring in the interested area.

5. Movement-aware node deployment:

Some mobile sensor nodes like AUVs (Autonomous Underwater Vehicles), UUVs (Un-manned Underwater Vehicles) or other kinds of underwater mobile sensor nodes are used. In [22] leader-follower solution is presented that relies on uncertainty model to trigger surfacing events. The control signal is updated based on these events, for which two different, control strategies are proposed. A Prediction Assisted Dynamic Placement (PADP) algorithm for surface gateway placement in mobile underwater sensor networks is proposed in [23]. The PADP algorithm predicts the position of the sensors at next several time steps using IMM estimator.

A tracing scheme IMM is applied to predict the sensors position underwater and branch and cut method is applied to maximize the coverage and employs a disjoint-set data

structure to control the connectivity of the nodes in the network. two moving patterns of the node are assumed: uniform motion: follows the straight line with at a constant speed, modeled by a Kalman filter, or with a synchronized turn with a constant turn rate and a constant speed, modeled by an extended Kalman filter. The two filters run in parallel. In the algorithm, to optimize the problem branch-and-cut is used, and to handel connectivity disjoint-set data structure is used. By deploying multiple surface gateways we can improve the effect of propagation delay and possibility of high error rate during transmission.

Surface gateway deployment problem is formulated as an integer linear programming (ILP) and solves the problem with heuristic approach [24]. Deployment optimization problems are solved by Greedy and greedy-interchange algorithms. The network lifetime can be improved by including the mobile data collector in underwater acoustic sensor networks [25]. Using mobile data collectors, authors has proposed two schemes for routing and placement of sensor nodes, one is Delay Tolerant Placement and Routing (DTPR) and the Delay Constrained Placement and Routing (DCPR) to increase the lifetime of the network. The data collectors collect data from the underwater sensors and send them to an on-shore sink node. The problem of finding the optimal placement of data collectors and determines the multi-hop routing paths to deliver data from underwater sensors to data collectors is formulated as integer linear programs (ILPs). This work is extended by author and proposes a scheme that extends the lifetime of the network with a guarantee of an upper bound on the delay.

The objective of maximizing the lifetime of the network without any limitation on the length of any path between a sensor node and a data collector was introduced in a new scheme proposed in [26], which maintains an upper bound for time a data unit can take in its way to a data collector. An algorithm for AUV collecting data using acoustic communication from an underwater sensor network is developed in [27]. The Communication-Constrained Data Collection Problem (CCDCP) is formulated in Traveling

Salesperson Problem (TSP). The proposed algorithm solve the problem optimally with high computation cost, and heuristically, based on existing approximation algorithms for TSP variant with probabilistic neighborhoods.

6. Conclusion

Underwater acoustic sensor network consists of sensor nodes, surface buoys and anchor nodes. A lot of work is being done in deployment of the nodes, localization of the sensor nodes to relate them to its spatial information, and the routing protocols. In this paper, we investigate the deployment algorithms and classify them in three broad categories namely:static node deployment, self-adjusting node deployment, and movement-aware node deployment according to the mobility of sensors in Underwater Acoustic Sensor networks (UASN). Static node deployment algorithms are divided in random and regular deployment algorithms and self-adjustingsensor deployment algorithms are further classified in uniform coverage and non-uniform coverage algorithms. The efficiency of deployment schemes affects the overall performance of the network.

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