Localization in Underwater Sensor Networks — Survey and Challenges

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ABSTRACT
In underwater sensor networks (UWSNs), determining the location of every sensor is important and the process of estimating the location of each node in a sensor network is known as localization. While various localization algorithms have been proposed for terrestrial sensor networks, there are relatively few localization schemes for UWSNs. The characteristics of underwater sensor networks are fundamentally different from that of terrestrial networks. Underwater acoustic channels are characterized by harsh physical layer environments with stringent bandwidth limitations. The variable speed of sound and the long propagation delays under water pose a unique set of challenges for localization in UWSN. This paper explores the different localization algorithms that are relevant to underwater sensor networks, and the challenges in meeting the requirements posed by emerging applications for such networks, e.g. offshore engineering.

Categories and Subject Descriptors
C.2 [**Computer Communication Networks**]: C.2.1 Network Architecture and Design – *Wireless Communications*; C.3 [**Special-Purpose and Application-based Systems**]: Underwater Sensor Networks – *localization.*

General Terms
Algorithms, Performance.

Keywords
Localization, Underwater Sensor Networks (UWSN), Positioning.

1. INTRODUCTION
Deployment of low cost wireless sensors is proving to be a promising technique for several applications. Underwater applications ranging from early warning systems for natural disasters (like tsunamis), ecosystem monitoring, oil drilling, and military surveillance have been looked into. The deployment and management of large scale wireless sensor networks is a challenge because of the limited processing capability and power constraints on each sensor. In recent literature, research issues pertaining to underwater sensor networks, from the physical layer to the application layer have been discussed [1].

An offshore engineering application scenario that could use an underwater sensor network is illustrated in the Figure 1. Exploration vessels used for oil drilling are generally huge and are anchored to the seabed with multiple anchors. For certain oil drilling applications, the water depth may be over 3000m. Smart sensors that can monitor environmental and system parameters can be deployed on the seabed. These work together with Remotely Operated Vehicles (ROV), which are controlled from the ship, or Autonomous Underwater Vehicles (AUV), which can navigate the deep waters autonomously based on a given set of rules and instructions. In such a system, the sensors, anchors, and ROVs/AUVs collect information from the seabed and feed the data to the vessel. The sensors and anchors can measure parameters like foundation strength and mooring tensions, and ideally provide accurate position references to the AUVs while they survey the deep sea environment with sophisticated surveillance equipment. A mechanism for data delivery from the seabed to the ship is required. In such a system, the location of the sensors, anchors and the AUVs need to be determined. This problem is especially challenging for deep water applications.

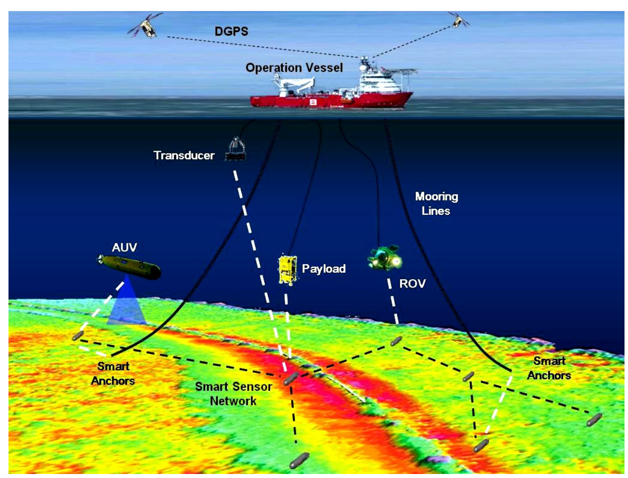

Figure 1. An example application scenario for underwater sensor networks

2. LOCALIZATION SCHEMES SURVEY
Sensor network data is typically interpreted with reference to a sensor's location, e.g. reporting the occurrence of an event, tracking of a moving object or monitoring the physical conditions

of a region. Localization underwater is challenging as Radio Frequency (RF) waves are heavily attenuated under water and hence, employing technology like GPS is not feasible. A number of localization schemes have been proposed to date which take into account a number of factors like the network topology, device capabilities, signal propagation models and energy requirements. Most localization schemes require the location of some nodes in the network to be known. Nodes whose locations are known are referred to as anchor nodes or reference nodes in the literature. The localization schemes that use reference nodes can be broadly classified into two categories: range-based schemes (schemes that use range or bearing information), and range-free schemes (schemes that do not use range or bearing information).

2.1 Range-based Schemes

In range-based schemes, precise distance or angle measurements are made to estimate the location of nodes in the network. Range-based schemes, which rely on range and/or bearing information, use Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) or Received Signal Strength Indicator (RSSI) to estimate their distances to other nodes in the system. UWB-based localization [2], GPS [3], and Cricket [4] are examples of schemes that use ToA or TDoA of acoustic or RF signals for localization in terrestrial sensor networks. In the context of underwater sensor networks, range-based schemes can be divided into three categories: infrastructure-based schemes, distributed positioning schemes and schemes that use *mobile beacons*. Each category is discussed in detail followed by the challenges faced by this class of schemes.

2.1.1 Infrastructure-based schemes

Infrastructure-based (anchor-based) localization systems are similar to the GPS scheme. In such a system, anchor nodes are deployed on the sea-bed at pre-determined locations. Surface buoys, whose locations are determined by GPS, might also serve as anchor nodes. The distance to multiple anchor nodes is computed by using the propagation time of the sound signals between the sensor or the AUV and the anchors. In many cases, the number of independent range measurements exceeds the number of unknown coordinates. In an over-determined system, the position estimate is made using least squares method. Such a scheme called Seaweb technology was implemented by the U. S. Navy and used to track AUVs [5]. The Seaweb technology was shown to track AUVs with an accuracy of 7-9 meters, in a roughly 3 km by 4 km area.

Prospector, a commercial system developed by Sonardyne, is also an infrastructure-based positioning system [9]. Four acoustic transponders are deployed on the seabed at known locations, with surface or sub-surface floats. Each transponder is deployed at a corner of a 500m×500m area. The system can track divers equipped with transceivers or ROVs with a high degree of accuracy in water depths ranging from 5 meters to 500 meters. Sonardyne claims that it can track objects with an accuracy of 300 mm, in a 500m×500m grid under shallow water conditions.

2.1.2 Distributed Positioning Schemes

Distributed positioning schemes are employed in cases where a positioning infrastructure is not available, i.e. anchor-free. In distributed positioning schemes, nodes are able to communicate only with their one-hop neighbors and compute the distances to their one-hop neighbors. Multilateration techniques, which encompass atomic, collaborative and iterative multilateration, are then used in a distributed manner to estimate the location of each sensor node. Distributed positioning algorithms generally have three positioning phases: the distance estimation phase, where nodes estimate the distances to their neighbors, the position estimation phase, where a system of linear equations is generally solved using a least squares approach to estimate the position of the node, and finally a refinement phase, where the accuracy of the algorithm is improved by using an iterative algorithm. The N-Hop Multilateration Scheme [6], the Hop-TERRAIN and Refinement Scheme [25], Ad Hoc Localization System (AHLoS) [20] and Ad Hoc Positioning System (APS) “Distance Propagation” and “Euclidian Propagation” Schemes [26] fall under this category.

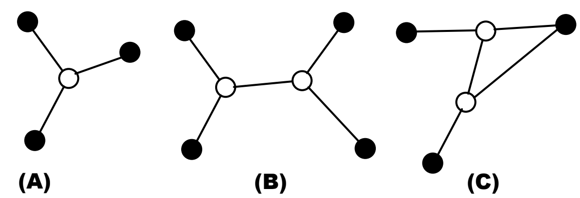

Figure 2. Position uniqueness conditions: (A) One hop multilateration (B) and (C) Two hop multilateration

The N-Hop Multilateration Scheme [6] discusses the requirements for location solution uniqueness in the one-hop, two-hop and n-hop case. Figure 2 shows the simple cases of one-hop and two-hop multilateration. In this scheme, initial estimates for all nodes are made using the conditions of position uniqueness, and the constraints obtained from distance measurements to neighboring nodes. A refinement process is then carried out using Kalman filters. In [25], initial estimates are obtained using an algorithm similar to the range-free scheme DV-Hop (discussed in Section B.1.1). Then, a least squares method is used to refine nodes' locations based on local computations. The AHLoS scheme [20] uses iterative multilateration where unknown nodes, which estimate their locations by triangulation, become beacon nodes. The problem with such a scheme is that the error propagates through the network as the number of hops from the anchor node increases.

In distributed positioning schemes, nodes estimate their distances to neighbors by making RSSI or ToA measurements. The paper [20] compares the advantages and disadvantages of using RSSI and ToA ranging in terrestrial sensor networks. RSSI based schemes can only provide a ranging accuracy of a few meters, while ToA based schemes can achieve ranging accuracy of a few centimeters. In underwater sensor networks, ToA based ranging is the preferred option as acoustics is the mode of communication between nodes.

Distributed positioning algorithms generally assume anchor nodes to be randomly distributed throughout the network, and the percentage of anchor nodes in the network to be quite high too (5-20%) [6]. In terrestrial sensor networks, deploying anchor nodes is not a challenge, as nodes equipped with GPS could act as anchor nodes. However, in the case of underwater sensor networks, setting up a backbone of randomly distributed anchor nodes, whose precise locations are known, is not a trivial problem.

The performance of different distributed positioning schemes in underwater sensor networks is compared in [7]. Under distributed positioning schemes, not all the nodes in the system are localized, even though the network might be fully connected. For example, the nodes which do not satisfy the position uniqueness conditions described in [6] might not be able to compute their locations.

2.1.3 Schemes that use Mobile Beacons/Anchors

Traditional range-based schemes have fixed anchor nodes whose locations are known. Schemes have been proposed which use mobile beacons whose locations are always known [8]. In this scheme, a mobile beacon traverses the sensor network while broadcasting beacon packets which contain the location coordinates of the beacon. Any node receiving the beacon packet will be able to infer that it must be somewhere near the mobile beacon with a certain probability. RSSI measurements of the received beacon packets are used for ranging purposes. After a number of packets have been received from the mobile beacon, Bayesian inference is used to determine the location of the node. In terrestrial networks, an autonomous vehicle installed with GPS could traverse the network and broadcast beacon packets. The challenge faced by an underwater network is that the location of the AUV itself might be unknown. The location of the AUV would have to be determined first using other means before it could be used for positioning nodes on the seabed.

A scheme that uses RSSI has to deal with problems caused by large variances in reading, multi-path fading, irregular signal propagation patterns and background interference. Such schemes may not be useful in the underwater scenario due to the large variances in RSSI. Alternatively, in the underwater domain, the ToA of the acoustic signals from the mobile beacon could be used for ranging purposes.

Commercial positioning solutions have been developed by Sonardyne [9] for shallow and deep water applications. As shown in Figure 1, a ship equipped with GPS suspends a transponder into the water. The sensor nodes dropped on the seabed are also equipped with acoustic transponders. The position of a node on the seabed is then calibrated by sailing the vessel over the area in which the nodes are dropped. The acoustic range and bearing data from the moving ship is used to localize the nodes. In this case, the ship serves as a mobile anchor and the localization process is typically carried out in less than 20 minutes. The scheme has been shown to work well in shallow waters. It has also been claimed that the nodes on the seabed are localized with an accuracy of within one meter, for water depths up to 500 meters. Based on the acoustic transponders on the nodes, the system can be deployed and positioned in water depth of 500-7000 meters. The nodes on the seabed whose locations are now known can help position AUVs, ROVs or divers equipped with transceivers using the infrastructure-based localization scheme described above. The acoustic range and bearing data from the ship equipped with GPS is also used to track and position ROVs attached to the ship.

2.1.4 Schemes without Anchor/Reference Points

The fourth class of schemes is different from the first three in that it does not require anchor nodes or beacon signals. In [28], a central server models the network as a series of equations representing proximity constraints between nodes, and then uses sophisticated optimization techniques to estimate the location of every node in the network. In [29], Capkun et al propose an infrastructure-less GPS-free positioning algorithm.

2.1.5 Problems and Challenges

Any scheme that relies on ToA or TDoA requires tight time synchronization between the transmitter and the receiver clocks. One simple way to achieve this in terrestrial networks is to use a radio signal for time synchronization. Savvides et al [20] and Kwon et al [21] use the difference in propagation times of acoustic and radio signals for calculating the distance. This works as the propagation speed of RF signals is five orders of magnitude higher than acoustic signals. The luxury of using RF signals for time synchronization is not available in the underwater scenario as RF waves do not propagate well underwater. Algorithms for time synchronization in underwater networks have been proposed by Syed et al [10]. Propagation latency is an important factor to consider for time synchronization algorithms in UWSNs and the localization accuracy depends on the accuracy with which we can estimate ToA or TDoA. In this aspect, signal processing and statistical filtering techniques can be used to improve the accuracy of acoustic range measurements [22]. The speed of sound is assumed to be constant in many schemes. However, the speed of sound is a function of temperature, salinity and depth [11]. Schemes that take into account the variation in the speed of sound are expected to perform better than those that just assume a uniform speed of 1500 m/s [7].

RSSI-based localization schemes for UWSNs need to take into account multipath effects due to surface reflection, bottom reflection and backscattering. The sea surface can act as a reflector or scatterer of sound depending on its roughness [23]. The roughness of the sea surface is dependent on the wave height and/or the wind speed measured above the sea surface, which are factors that constantly vary. Just like the sea surface, the seabed can also have a reflecting or scattering effect on acoustic waves. Experiments reported in [24] have shown that multipath effects can be modeled as Rayleigh fading in shallow water environments. Acoustic signals, apart from undergoing large scale spherical or cylindrical losses under water, also undergo attenuation losses and losses due to air bubbles, and are subjected to external sources of noise like shrimp noise [23]. All these factors need to be taken into account for RSSI-based ranging schemes. Due to the large variances in RSSI, ToA or TDoA based ranging techniques are generally the preferred mode of range-based schemes in underwater sensor networks.

Several range-based localization schemes for terrestrial sensor networks are based on AoA, where sensor nodes calculate the relative angles between neighboring nodes. However, schemes that use AoA entail sensors and anchor nodes to be equipped with special antenna configurations which may not be feasible to embed on each sensor. Such schemes also involve solving complex non-linear equations [12].

2.2 Range-free Schemes

Range-free localization schemes do not use range or bearing information; that is, they do not make use of any of the techniques mentioned above (ToA, TDoA and AoA) to estimate distances to other nodes. The centroid scheme [13], DV-Hop [14] and Density aware Hop-count Localization (DHL) [15] fall under this category. The advantage of these schemes lies in their simplicity, as sensors do not need to make any TDoA, ToA, RSSI or AoA measurements and, schemes like DHL and DV-Hop have been successfully implemented and tested on typical sensor devices [30] like the Crossbow MICAZ motes [31]. However, range free schemes only provide a coarse estimate of a node's location. Range-free schemes can be broadly classified into hopcount-based schemes and area-based schemes.

2.2.1 Hopcount based Schemes

In this section, we consider hopcount-based schemes where the anchor nodes are placed at the corners or along the boundaries of a square grid.

DV-Hop is one of the most basic range-free schemes, and it first employs a classical distance vector exchange so that all nodes in the network get distances, in number of hops, to the anchor nodes. Each node maintains a table and exchanges updates only with its neighbors. Once a landmark (i.e. an anchor) gets distances to other landmarks, it estimates an average distance for one hop, which is then propagated as a correction to the entire network. Upon receiving the correction, an arbitrary node then estimates its distances to the landmarks, in meters, which can be used to perform triangulation [14]. The DV-Hop algorithm performs well only in networks that uniform and dense node distributions.

For actual deployments where the node distribution is more likely to be non-uniform and sparse in certain regions, schemes like Density-aware Hop-count Localization (DHL) [15] have been proposed to improve the accuracy of location estimation when the node distribution in the network is not uniform. This scheme takes into account both the density of a node's neighbourhood when computing the average hop distance, as well as, the fact that error in distance estimation tends to accumulate with the increase of path length.

Iterative multilateration, the process where unknown nodes which have estimated their locations become anchor nodes, must be carefully employed in range free hopcount-based schemes. For example, in a network with anchor nodes placed at the corners of a square grid, it is observed that the error is higher along the boundaries and lower in the middle of the region. Based on this observation, a Selective Iterative Multilateration (SIM) algorithm [27] is proposed where new anchor nodes are selected judiciously such that their initial position estimates are sufficiently accurate.

2.2.2 Centroid Scheme

In this scheme, anchor nodes are placed to form a rectangular mesh. The anchor nodes send out beacon signals at periodic intervals with their respective locations. From the beacon signals received, a receiver node infers proximity to a collection of anchor nodes. The location of the node is then estimated to be the centroid of the anchor nodes that it can receive beacon packets from. A high concentration of anchor nodes is required for this scheme to work well. Also, such a scheme would be hard to implement in the underwater context as it would require setting up a rectangular mesh of anchor nodes on the seabed.

2.2.3 Area-based Localization

In very large and dense wireless sensor networks, it may not be feasible to accurately measure the exact location of every sensor and furthermore, a coarse estimate of the sensors' locations may suffice for most applications. The Area Localization Scheme (ALS) [16] and Approximate Point in Triangle (APIT) [17] are examples of area-based schemes. ALS and APIT approximate the area in which a node is located, rather than the exact location. The performance of ALS and APIT in a 500m×500m UWSN is compared in [16].

2.2.3.1 Area Localization Scheme (ALS)

ALS [16] is a centralized range-free scheme that provides an estimation of a sensor's location within a certain area, rather than the exact coordinates of the sensor. Anchor nodes send out beacon signals at varying power levels and based on the ranges of the different power levels of the anchor nodes, the grid is divided into multiple smaller areas. The sensors measure the lowest power level that they receive from each anchor node and this information is forwarded with the sensor data to the sink for processing. This information is represented by an *n*-dimensional coordinate, where the i^{th} coordinate represents the lowest power level from the i^{th} anchor node. A very simple case of ALS is shown in Figure 3 below.

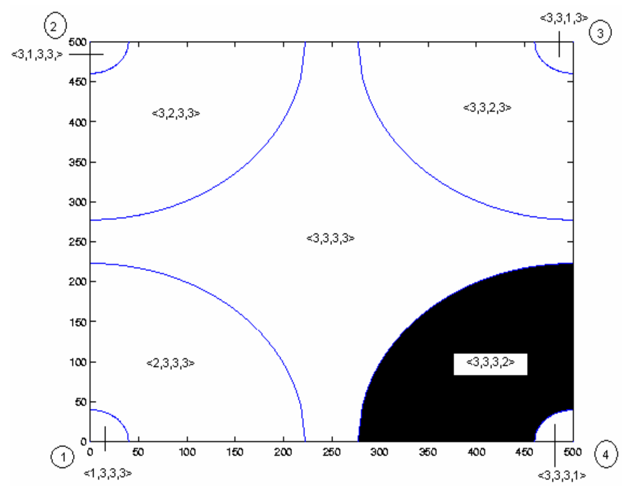

Figure 3. An example of the ALS. Shaded region is <3, 3, 3, 2>

For example, consider a square area with anchor nodes at the four corners as shown. Each anchor node sends out beacon signals at three distinct power levels. The smallest power level is represented by the integer 1 while the highest power level is represented by the integer 3. For each node, the contour lines represent the farthest distances that the beacon signals at each power level can travel. Contour lines for beacon power levels 1 and 2 are drawn. The power level 3 for each corner anchor node extends beyond the corner that is diagonally opposite to it and so, its corresponding contour line is not seen on the area. Thus, for each anchor node, the two contour lines corresponding to power levels 1 and 2 divide the area into three regions. For a sensor node in the shaded region, the lowest power level received from anchor nodes 1, 2 and 3 is 3. The sensor node also receives beacon signals at power levels 2 and 3 from anchor node 4. So, the lowest power level received by the sensor from anchor node 4 is 2. As a result, the shaded region in the figure can be represented by the unique signal coordinate <3,3,3,2>. Similarly, every other region in the square area can be represented by a unique signal coordinate, as shown in Figure 3.

The area in which the node is located is computed by the server or anchor to determine the sensor's location. The granularity of the scheme is determined by the size of areas, which the sensor nodes fall within and this is adjusted by varying a number of power levels used.

2.2.3.2 Approximate Point In Triangle (APIT)

In the APIT scheme, a node chooses three anchors from all audible anchors (anchors from which beacons were received) and tests whether it is inside the triangle region formed by these three anchors. The theoretical method used to determine whether a point is inside a triangle or not is called the Point-In-Triangle (PIT) test. The PIT test can be carried out only under ideal physical layer conditions, when every node in the network is mobile and can move around its own position. Due to the infeasibility of conducting such a test, an APIT (Approximate Point in Triangle) test is proposed [17]. APIT uses RSSI information of beacon signals to determine whether it is inside or outside a given triangle. The PIT or APIT tests are carried out with different audible anchor combinations until all combinations are exhausted. The information is then processed by a central server to narrow down the possible area in which a target node resides.

2.2.4 Challenges of range-free schemes

Range-free schemes offer a less precise estimate of location compared to range-based schemes. Range-free schemes are useful in the context of terrestrial sensor networks, where sensor nodes might not be capable of sending acoustic signals for ranging purposes. In the case of underwater sensor networks, acoustic signals can be used for fairly accurate ranging. However, there are scenarios where a coarse estimate of the node's location might suffice. For example, geographical routing protocols [18] could use the coarse location information obtained from range-free schemes for establishing source-destination paths.

2.3 Signal Processing/Probabilistic Schemes

The third class of schemes uses signal processing techniques or probabilistic schemes to do localization. The U.S. Wireless Corporation fingerprinting scheme [19] falls under this category. Instead of exploiting signal timing or signal strength, this scheme relies on the received signal structure characteristics to do localization. By combining the multi-path pattern with other signal characteristics, the algorithm creates a signature unique for every given location in the area. This can be achieved by driving a vehicle through the area and acquiring the signal characteristic information. By comparing the received signal characteristic to all the fingerprints in the database, a node's location can be determined. The major drawback of this technique is the substantial effort needed for generation of the signal signature database. Hence, it is not suited for the ad hoc deployment scenarios in consideration.

3. COMPARISON OF LOCALIZATION SCHEMES

Table 1 compares the different localization schemes that have been discussed in this paper. Infrastructure-based positioning systems are suitable for shallow water applications as anchor nodes can be placed on the seabed at known locations. Alternatively, the position of the anchor nodes on the seabed can be calibrated using a mobile ship equipped with GPS (mobile beacon scheme). The anchor nodes on the seabed can then help position AUVs, ROVs and other nodes in the system. Positioning can be done with a high level of accuracy with any of the range-based schemes described above, if a sufficient number of anchor nodes are placed on the seabed.

The problem is a lot more challenging for deep sea applications because it is difficult to deploy a lot of anchor nodes in precise locations. One solution for deep water applications would be to suspend a ROV deep into the sea, position the ROV with respect to the ship and then use the ROV to position the sensor nodes on the seabed. Error propagation would be a problem with such a solution, as the error in the location of the ROV would be propagated to the UWSN.

Schemes that require a small percentage of anchor nodes would be useful in deep water applications. If the precise locations of the nodes are not required, range-free schemes like ALS or DHL could be used. For example, if the location of the nodes is to be estimated only for routing data efficiently from the sensors to the sink, range-free schemes could be used.

4. LOCALIZATION FOR UWSNS IN OFFSHORE ENGINEERING

Accurate localization for underwater construction activities is a big challenge in the offshore engineering community. This technical challenge increases with the drive towards oil production in deeper water with unknown or unstructured environments where the mudline can be characterized as having constantly changing configuration.

4.1 Deepwater Installation

Subsea templates (Figure 4), christmas trees and manifolds have to be installed accurately in a specified spatial position and compass heading within tight limits, including rotational, vertical and lateral measurements. The tolerances for a typical subsea installation are within 25cm of design location and within 2.5 degrees of design heading for large templates and are more stringent for the installation of manifolds into the templates. The resolution of the UWSN needs to be precise to enable accurate installation of the structures in the proximity of other hardware. The signals from the UWSN can be fed back to "intelligent crane hooks" or ROV operators which can actively control the positioning of the payload or relayed to the bridge of the installation vessel for overall maneuvering. Due to the high daily costs of the crane barge and the marine spread for the installation operation, it is essential that the acoustic positioning system perform with 100% reliability during the brief weather windows in which installations could be safely performed.

Table 1. Comparison of different localization schemes

Schemes	Range based or Range Free	Accuracy	Distributed or Centralized	Placement of anchor nodes	% of anchor nodes	Additional Comments
Infrastructure based positioning systems	Range based, ToA, TDoA	Accurate: 1 to10 m for 3 km × 4 km area. Accuracy depends on area size	Distributed	At the corners of a square grid	Small	Requires placement of anchor nodes on sea-bed
Distributed positioning	Range based, ToA, TDoA	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	Distributed randomly	High (5% to 20% of nodes)	Requires placement of anchor nodes on sea-bed
Mobile Beacons	Range based, ToA	Accurate: < 1 m, for shallow water of <500 m (Sonardyne)	Distributed	Only one anchor	Low	The mobile beacon could be a ship equipped with GPS, or an AUV/ROV whose location is known
DV-Hop	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	At the corners of a square grid	Low	Simple to implement
Centroid based localization	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed	In a grid structure	High (High for good performance)	Simple to implement, but requires placement of anchors in a square mesh
ALS	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Centralized	At the corners of a square grid	Low	Anchor nodes must be able to cover area in consideration. Simple to implement
APIT	Range Free	Not Accurate: 0.5*(Radio Range) to 1*(Radio Range)	Distributed or Centralized	Randomly distributed	High (High for good performance)	Anchor nodes must be able to cover area in consideration. Simple to implement
Fingerprinting, Signal Processing based schemes	Range based, RSSI	Accurate, but only good for small areas	Centralized	No anchor nodes	N/A	Very difficult to implement in the underwater domain because of training phase

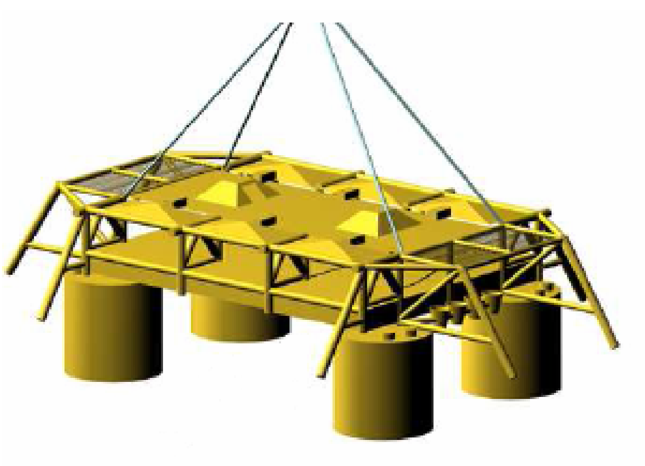

Figure 4. A subsea template

4.2 Metrology

Metrological measurements have to be performed after the placement of the structures on the seabed to measure the dimensions between adjacent templates or subsea structures. This dimensional control serves to facilitate accurate fabrication of the connecting spool pieces between the structures. An UWSN which can provide precision measurements for installation can potentially be reused for such metrological purposes. The measurement from the UWSNs can expedite the construction phase by reducing the need for an additional metrology process resulting in substantial time and cost savings.

4.3 Reliability Monitoring of Mooring System

There are several types of mooring systems employed by the offshore industry for Floating Production Storage and Offloading (FPSO) vessels and other drilling and production vessels. The knowledge of anchor positions can be valuable in the prediction of dynamic behaviors of the mooring systems such as Turret, Single Point Mooring and Spread Mooring Systems.

Vertically loaded anchors (VLA) are currently used in the deepwater with applications to drilling and operations amongst other anchors (Figure 1). A typical VLA has to be installed at long scope with an uplift angle limit of 15 degrees at the seabed. Also, at the point of maximum holding capacity, further loading results in the anchor being pulled out to the seabed level with decreasing holding capacity. Information pertaining to the position and inclination of the anchors relative to the vessel will enable consistent monitoring of system reliability, safety and optimization.

Although several moored systems were already installed as a positioning system of FPSO, feedback of position data and soil data from UWSN can be investigated to enhance safety and lower cost.

5. CONCLUSIONS

Localization for terrestrial sensor networks has been studied in great detail. However, the problem of localization in underwater sensor networks poses a new set of challenges because of the acoustic transmission medium. This paper surveys the different localization algorithms that can be applied to the domain of UWSNs, which can be broadly classified into range-based and range-free schemes. The different schemes are compared, and their advantages and disadvantages discussed. Many of the localization schemes discussed here are shown to work in simulation, and their performance needs to be evaluated in underwater systems. Finally, localization is discussed in the application domain of UWSNs in offshore engineering.

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