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Localization Schemes for Underwater Sensor networks-A Survey

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***Abstract*—Underwater Sensor networks are gaining popularity in the last few years due to the advancement of the sensor network technology and the wide range of terrestrial and underwater applications. Underwater sensor networks have several common properties with the terrestrial sensor network still, they are different from the terrestrial sensor networks due to the acoustic communication channel and the mobility of the sensor nodes. The sensor nodes need to be localized to relate the collected data of the sensor node with its physical location. In this paper, we have reviewed some localization scheme for underwater sensor networks. The localization schemes are divided into three categories namely: Stationary anchor nodes assisted, Non-propeller mobile anchor node assisted, and Propeller mobile anchor assisted.**

***Keywords*—Underwater Sensor Network,Localization,Wireless Networks, Acoustic Signals.**

1. INTRODUCTION

As the most of the part of the earth is covered with water, there is a need for some mechanism to be connected with the underwater environment. Underwater Sensor Network (UWSN) is the way to connect this less explored area with the rest of the world. In Underwater sensor networks sensors are deployed randomly, which collaborate with each other to collect scientific data or to perform monitoring task for the application area [1][2]. The sensor nodes communicate with each other using acoustic communication channel. Unmanned Underwater vehicles (UUVs) and Autonomous Underwater Vehicles (AUVs) also assist the monitoring task[3]. AUVs moves slowly underwater following a predefined path in the network, and its movement is also controllable.

Underwater sensor networks are attracting researchers because of a large number of applications, includes ocean sampling, natural disaster prevention, military, oil mining, pollution monitoring etc. Although there are some basic common characteristics of wireless sensor networks like the requirement of a large number of sensor, and limited energy, underwater sensor networks are different from terrestrial sensor networks[4][5]. Firstly, the communication between the nodes is done through the acoustic communication channel which has higher error rate and lower bandwidth[6]. Secondly, the sensor nodes are mobile due to the water current which results in a constant change in network topology.

The localization scheme can be divided into two categories Range-based localization scheme and Range-free localization scheme. In range-based localization scheme, the localization is performed by calculating the distance or angle with respect to a reference point. The angle and distance can be calculated by one of the following technique: ToA,TDoA,RSSI,and AoA. TDoA(Time Difference of Arrival) calculates the difference between the arrival of two signals. ToA(Time of Arrival) calculates the difference between the sending and receiving time of the signal. AoA(Angle of Arrival) is the angle between the recieved signal with a reference direction. RSSI(Receive Signal Strength Indicator) calculates the distance based on the propagation delay of the signal[7]. In range free localization schemes distance or angle estimation is performed.

As the nodes are deployed in the network to collect information from the water, a track of the physical location of the sensor nodes is also necessary to correlate the data with its spatial information. Localization schemes are required to find the position of the sensor nodes underwater. Although, a rich amount of localization methods has been developed for terrestrial sensor networks these schemes are not applicable to underwater sensor networks due to different environmental conditions.

In this paper, some of the localization schemes are summarized. According to the assistance in the localization process, localization scheme can be broadly divided into three categories namely: Stationary anchor node Assisted, Non-Propellers mobile anchor node Assisted, and Propeller mobile anchor node assisted localization schemes. The rest of paper is organized as follows: Section 2 summarizes the localization scheme for the underwater sensor network. In section 3 localization scheme assisted by stationary anchor are summarized. Section 4 gives a details of localization scheme assisted by Non-propeller Mobile anchor nodes. The localization schemes assisted by propeller mobile anchor nodes are presented in section 5. Section 6 gives a concluding remarks.

2. Localization Schemes

In an underwater sensor networks, there are mainly four types of node: anchor nodes, surface buoys, AUV and Sensor nodes. Surface buoys are GPS enabled, so they can get their location information directly from the satellite. Anchor nodes are wired with surface buoys or with the surface buoys. They can communicate directly with the surface buoys to get their location underwater. AUVs (Autonomous Underwater Vehicles) moves among the network following a predefined path. AUVs get their location while floating on the surface of the sea then they dive underwater. Sensor nodes are mobile and float freely underwater. Sensor nodes have relatively low power and computational capabilities. The major task of the localization scheme is to find the location of these sensor nodes. Based on properties of anchor nodes, localization schemes are divided into four categories namely: Stationary anchor nodes assisted, Non-propeller mobile node assisted, Propeller mobile assisted and self-localized localization scheme.

3. Stationary Anchor Node Assisted Localization Schemes

The localization scheme which are assisted by the anchor nodes:

An Area Localization Scheme (ALS) was first proposed for terrestrial sensor network.[8]. Inspired by the concept of stationary anchor nodes, authors proposed a similar localization scheme for underwater localization scheme in [9]. The anchor nodes are stationary and they are capable of sending the localization message at different power levels. The anchor node broadcast the message in increasing power, where the highest level is enough to cover the entire region of interest. Each node records the message with the ID of the anchor node and the average of the lowest and highest power level it receives from that anchor nodes. According to these value, a coarse-grain estimation of the location is performed.

In Hyperbole-based Localization (HL) proposed in [10][11], instead of using traditional circle-based distance estimation method which assumes the real world to be perfect, the hyperbola-based approach is used. In circle-based approach, each anchor node calculates its distance from the event and a circle is drawn assuming it the radius of the circle. The intersection point of the circles is assumed as the location of an event. figure 1a shows the circle-cased approach and the hyperbola-based approach is shown in figure 1b.

If an event occurs at time t_i, then the radius of the circle distance between the event and the anchor nodes is calculated as follows:

$$r_i = v \times (t_i - t_e)(i = 1, 2, 3) \quad (1)$$

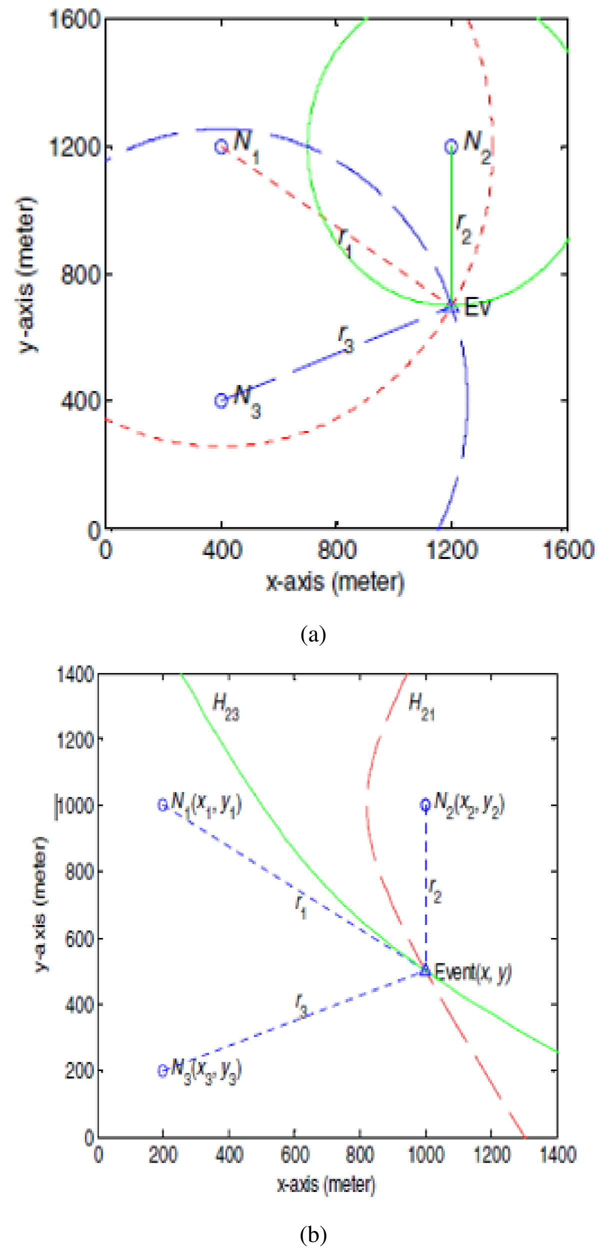

Figure 1: (a) Circle-based approach, (b)Hyperbola-based approach[11]

Where r_1, r_2, r_3 denotes the distance between the event and the nodes N_1, N_2, and N_3 respectively. With the known positions of the anchor nodes (x_i, y_i)

$$v \times (t_i - t_e) = \sqrt{(x_i - x)^2 + (y_i - y)^2}(i = 1, 2, 3) \quad (2)$$

A Large-Scale Hierarchical Localization Scheme for underwater acoustic sensor network is proposed in [12]. To localize the sensor nodes, anchor nodes (which knows their location from the surface boys) broadcast their position in the network. The sensor nodes hearing the message sends it to their peer sensor nodes and measure the distance from the neighbouring nodes using ToA method. The Sensor nodes after having the distance information from at least three anchor nodes calculate its coordinates using lateration. Although it is a simple localization scheme it suffers from high energy consumption due to a large number of beacon message exchange.

In [13][14], Underwater Positioning Scheme (UPS) has been proposed for the stationary underwater acoustic sensor network. The localization process is performed by four anchor nodes which send beacon message sequentially. To initiate the process an anchor node is selected as a master node among these four anchor nodes. As shown in the figure 2 there are four anchor nodes A, B, C, and D. Node A is selected as a master anchor node. The master node A sends the beacon signal, anchor node B after hearing the beacon message send a packet containing the time difference of sending time and receiving time of the beacon signal. Node B, C, and D also repeat the same process in sequence. The sensor node S calculates the TDoA according to these time differences, and calculate its location based on the positions of anchor nodes and the range information. The scheme assumes that the four anchor nodes are sufficient to cover the entire interested area which limits the area of interest, also it does not provide a unique location. A localization scheme Wide Coverage Positing Scheme (WPS) developed in [15] is an extension of UPS. The scheme generalized the UPS scheme with N anchor nodes. It introduces the fifth anchor node to get a unique solution. To increase the area of interest of UPS scheme an iterative localization phase and complementary phase are added in Large-Scale Localization Scheme (LSLS) proposed in [16]. In the iterative localization phase, a group of localized nodes is selected to be anchor nodes in UPS scheme. In the complementary phase, unlocalized nodes are located using a different set of anchor nodes after the request from unlocalized nodes.

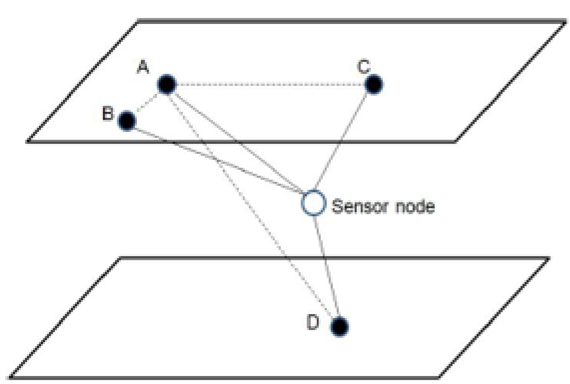

Figure 2: UPS Localization Scheme

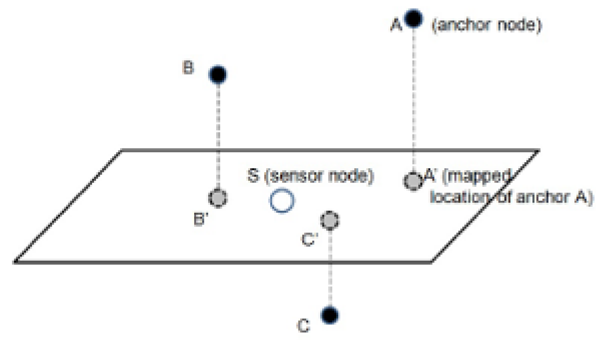

Figure 3: Projection technique used in USP [17] [18]

A three-dimensional localization scheme Underwater Sensor Positioning (USP) for the underwater sensor network is proposed in [17] [18]. The scheme assumes that the sensor nodes are equipped with pressure sensor by which gives the depth information of the sensor node. Using the depth information of the sensor nodes the anchor nodes are projected to a horizontal plane at the depth of the to-be-localized node as shown in the figure 3. If some of the anchor nodes have overlapped projection than a different set of anchor nodes is selected for localization process. After a predefined time, interval, each localized nodes broadcast their location and update their location according to the broadcast message received from the neighboring nodes. Initially, the to-be-localized node tries to get the location using two anchor nodes by the bilateration method, if the unique solution is not provided by the bilateration method it has to wait for the message from another anchor node.

In [19], the author proposed Scalable Localization with Mobility Prediction (SLMP). The scheme consists of three types of nodes surface buoys, anchor nodes, and ordinary sensor nodes. Surface buoys get their location through GPS and sent it to anchor nodes in the network. The anchor nodes estimate their location using the location information of the surface buoys and the mobility pattern of the anchor node. After a predefined time-interval, the anchor nodes check the validity of its mobility pattern. To check the validity sensor node after predicting the location estimates its location by lateration using surface buoys location and the distance between anchor node and surface buoy. If the difference between estimated and predicted value exceeded a given threshold value, then the anchor node updates its mobility pattern with its mobility prediction algorithm. The anchor broadcast the new mobility pattern and its coordinates to the sensor nodes. The sensor nodes after hearing the message update their mobility pattern and location.

4. Using Non-Propeller Mobile Anchor nodes

Propellers can be defined as mobile anchor nodes which dives and rise underwater and broadcast its location to the sensor nodes in the network to assist the localization process.

In [20] authors proposed a localization scheme Dive and rise (DNR) which reduces the required number of anchor nodes by introducing a few number of mobile anchor nodes. The mobile anchors dive into the water by extra wait on it after reaching to a predefine-depth it starts its reverse journey to the surface as shown in figure 4. The mobile anchor nodes get their location on the surface of the sea through GPS and broadcast it into the network to assist the localization process while going down and up. The sensor nodes silently listen to the broadcast message and calculate their position based on one-way ToA technique. Although, the scheme was developed to reduce the communication cost of the static anchor nodes and the number of required anchor nodes the localization scheme suffers from the high cost of hardware. The domain area of $1000m \times 1000m \times 1000m$ requires 25 DNR beacons for which 25 moving equipment and 25 GPS are required which increases the cost of localization schemes. In [21], the authors proposed a hierarchical localization scheme Detachable Elevator Transceiver Localization (DETL) which includes four types of nodes namely surface buoys, Detachable Elevator Transceivers (DETs), anchor nodes, and ordinary nodes. Surface buoys float on the surface and get their location from GPS. DETs are attached to the surface and moves downward and upward in the water. Anchor nodes are stationary node and calculate their location by lateration or min-max techniques on receiving at least three beacon messages from DETs. Anchor nodes after getting their location help the ordinary nodes to get localized. A localization scheme Multi-Stage Localization (MSL) proposed in [22], uses the mobile anchor node DNR with a multistage process. The DNR takes a long time to dive and rise in water so the localization process is speed ups using multi-stage process.

5. Using propeller mobile anchor nodes

The underwater sensor networks are also consisting of Unmanned Underwater Vehicles (UUVs) and Autonomous Underwater Vehicles (AUVs) which moves in the network in a controllable manner. Some of the localization scheme assisted by these vehicles are listed below.

An AUV aided localization(AAL) scheme for Underwater acoustic sensor network is proposed in [23]. The structure of the network model contains a large number of sensor node and one AUV. Sensor nodes float freely in the network at different depth of the sea. AUV moves among the sensor node and broadcast messages in the network. The localization scheme does not require time synchronization.

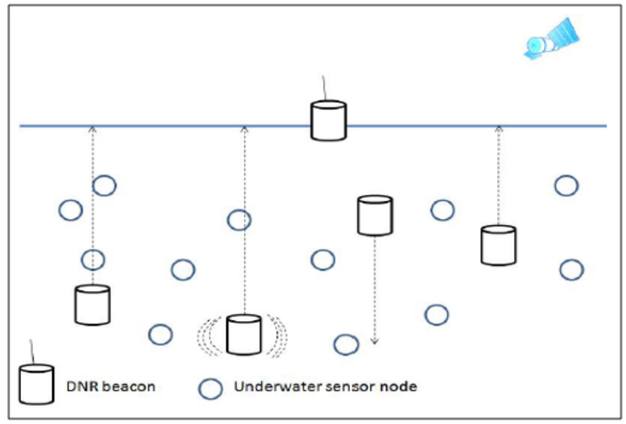

Figure 4: Network model of DNR Loclaization

The communication between AUV and the sensor network is performed by message passing. The AUV sends a wake-up message to inform the sensor nodes about its presence. After hearing the message, the sensor nodes in the communication range of the AUV sends a request packet to it. In response to the message, AUV sends a response message to the sensor containing the coordinates of it. Using the *Round Trip Propagation Delay (RTPD)* of the messages distance between the AUV and the sensor nodes is calculated by the following equation 3:

$$d = S * (RTPD)/2 \tag{3}$$

Where d is distance between AUV and the sensor node, $RTPD$ is round trip propagation delay, and S is the speed of sound. Using distance, the coordinates of the sensor node is calculated by bounded box technique.

In localization scheme Using Directional Beacon (UDB) proposed in [24], the directional beacon signal is used in place of traditional omnidirectional beacon signal. The network consists of the sensor nodes and the AUV. The beacon signals send by AUV are directed by directional antenna attached to it as shown in the figure 5. The sensor nodes are stationary nodes they are anchored at the surface of the sea or deployed at the seabed. The sensor nodes silently listen to the beacon message which reduces the communication cost of the scheme. Based on the beacon signal received the sensor node calculates its distance to the AUV and hence estimates its location.

The localization scheme for 2-dimensional sensor network UDB is extended for 3-Dimensional underwater sensor network in Localization using Directional Beacon (LDB) scheme is proposed in [25]. Instead of stationary sensor nodes of UDB, the nodes are deployed at the different depth of the sea. The AUV sends the beacon messages which are directed by the directional antenna as in UDB. The AUV gets its location at the surface of the sea by GPS and dives up to a predefined depth and starts sending the beacon messages in the network including the coordinates

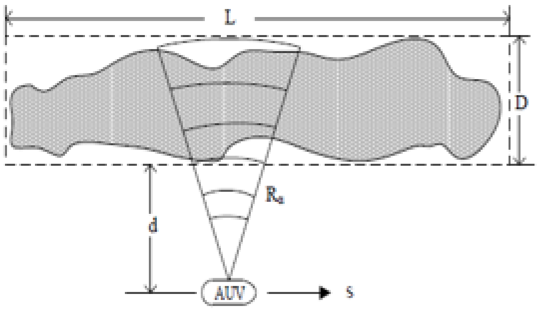

Figure 5: Moving AUV with directional beacon in UDB and LDB[24]

of it and angle of the beacon angle. The sensor nodes calculate their location by first-heard and the last-heard message from the AUV.

6. Conclusion

Underwater Acoustic Sensor network has gain popularity in past few years which needs to develop a localization scheme for node tracking and maintenance. There are a number of localization schemes developed for terrestrial sensor network which cannot be applied for underwater sensor networks due to different environmental conditions. In this paper we give a detail survey of localization schemes developed for Underwater Sensor Networks.

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