

Localization Techniques and Their Challenges in Underwater Wireless Sensor Networks

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Abstract-- Underwater Wireless Sensor Networks (UWSNs) are widely used to explore aqueous environment. In UWSN, determining the location of sensor nodes is a critical issue. Sensed data is meaningful only when sensing node is localized. There are many techniques available for localization in Wireless Sensor Network (WSN) but they are not applicable in UWSN. GPS signals cannot be used underwater for localization. Underwater communication is based on acoustic waves. This paper explores the different localization schemes available for UWSN and challenges to meet the localization issue. Node mobility, high propagation delay, time synchronization and high bit error rate are the main challenges that need to be addressed.

Keywords- Underwater Wireless Sensor Network, Localization, Acoustic Communication.

I. INTRODUCTION

Underwater Sensor Networks (USNs) are a promising solution for exploring aqueous environment. Many applications such as ecosystem monitoring, seismic monitoring for oil extraction [1], pollution and water quality control, disaster prevention, military surveillance etc. uses USNs. USNs use acoustic signals for communication because radio waves get attenuated in underwater environment. Large propagation delay, high bit error rate, low data rate and low bandwidth are characteristics of acoustic communication [3].

Architecture of underwater network is application dependent. A general architecture of underwater sensor network is shown in Fig. 1. UWSN consists of sensor nodes, supernodes, base station, autonomous underwater vehicles (AUV), remotely operated vehicles (ROV) controlled by a base station etc. Sensor nodes collect data by monitoring underwater deployment area and use acoustic link to relay that data to sea floor base station. Base station uses acoustic signals to communicate with underwater nodes and use radio signals to relay data to a user station for processing. Sensor nodes should be energy efficient because power management is a critical issue in underwater network.

There are many critical issues in underwater network like energy efficiency, time synchronization, localization, routing protocol etc. need to be resolve. Localization of sensor nodes is necessary because sensed data is only meaningful when sensor node is localized. There are many localization schemes proposed for wireless sensor network but these cannot be directly applied to USN because

characteristics of USN are different from that of WSN. As GPS uses radio waves which get attenuated underwater, so it cannot be used for underwater localization. In this paper, we discussed different localization schemes proposed for USN. These localization schemes are divided into two categories: Range-based schemes and Range-free schemes [4], [5]. These schemes are discussed separately.

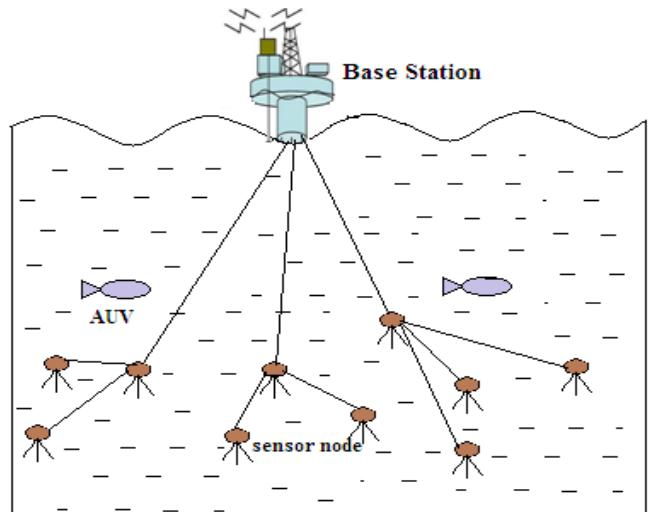


Fig. 1 Common architecture of UWSN

Rest of paper is organized as: In section 2, challenges faced in USN localization are discussed. Section 3 contains description of range-based schemes. In section 4, range-free schemes are described. Section 5 contains comparison of localization schemes and finally section 6 concludes the paper.

II. CHALLENGES IN UNDERWATER LOCALIZATION

Main challenges [2] in underwater localization are:

A. Node Deployment

Deployment of sensor and reference nodes is difficult and costly in deep sea environment.

B. Node mobility

Underwater nodes get drifted by underwater current and others activities. Speed of current is time variable and difficult to predict. If a node get moved during localization process, its position estimation gone wrong.

C. Change in Signal Strength

Strength of acoustic signal gets affected by many factors like Doppler shift, multipath propagation, attenuation and external noise. RSSI based localization schemes needs to consider all these factors as they can decrease the performance of the scheme.

D. Time Synchronization

Many localization schemes assume that nodes are synchronized. Time synchronization is difficult to achieve in underwater scenario due to long propagation delay and variable sound speed. As radio signals cannot propagate underwater, so GPS service is also not available.

E. Variation in Sound Speed

Localization schemes assume constant sound speed but it is variable and depends on temperature, pressure and salinity. Variations in any one of these factors alter the sound speed. It may introduce error in distance estimation and accuracy of the scheme may decrease.

F. Acoustic channel characteristics

Speed of sound in water is five orders of magnitude lower than radio wave. So propagation delay is higher. Bandwidth is limited and it depends on transmission range and frequency. Data rate is low compared to radio and bit error rate is higher.

III. RANGE-BASED LOCALIZATION SCHEMES

Range-based localization schemes use range or bearing information for position estimation. These may use Time of Arrival (TOA), Time Difference of Arrival (TDOA) or Received Signal Strength Indicator (RSSI) for distance estimation. In most of cases, TOA is used. Location of some nodes in network is known in advance which are called anchor node or reference node. These are used to localize other unlocalized nodes in the network. First of all, distance is measured between sensor node and some anchor nodes. Then these distance measurements are used to find node's position coordinates. To find d coordinates, d+1 distance measurements are required.

In paper [11], an anchor free localization algorithm (AFLA) is proposed. In this scheme, no anchor nodes are deployed. Sensor nodes are connected to fixed anchors by cable at sea bottom to avoid them to move away from monitoring area. So movement of nodes is active restricted. It is self localization algorithm that makes use of relationship of adjacent nodes for position estimation. Node mobility is considered and it is applicable to both static and dynamic environment.

A hierarchical localization approach (LSL) for large scale 3D network is proposed in [10]. The whole localization process is divided into two subprocesses: anchor node localization and ordinary node localization. Any existing technique can be used for anchor node localization. For ordinary node localization, a distributed approach is used that integrated 3D Euclidean distance estimation with recursive location estimation method.

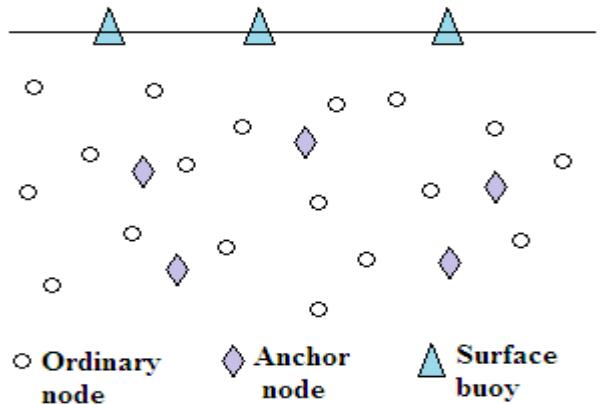


Fig. 2 Nodes deployment in hierarchical localization [10]

There are three types of nodes: surface buoy, anchor node and ordinary node as shown in Fig. 2. Surface buoys get their location through GPS and helps in anchor nodes localization. Anchor nodes in turn are used to localize ordinary nodes. High localization coverage with low communication overhead can be achieved by this scheme.

A time synchronization free localization scheme (LSLS) for large scale UWSN is proposed in paper [14]. Three surface buoys are deployed that can hear each other. It relies on time difference of arrival measured at a sensor node from three anchor nodes that can hear each other. Reactive beaconing is used for time synchronization. Sensor node projects anchor nodes to its horizontal plane and use trilateration technique to find its coordinates. An iterative procedure is followed in which localized nodes become reference nodes in next round to maximize coverage. Effect of variable sound speed on the scheme is evaluated. High node density is required for large area coverage.

A distributed bilateration projection based method for 3D UWSN called underwater sensor positioning (USP) is introduced in paper [15]. In it, 3D localization problem is transformed to its 2D counterpart by employing depth information of sensor nodes as shown in Fig. 3. The authors proved that nondegenerative projection preserves network localizability and all k-lateration techniques are equivalent. Bilateration and iterative localization is used to localize all nodes in 3D network with the help of three surface buoys. A node is localizable in 2D plane if it is localizable in 3D plane. Bilateration can localize more nodes than can be localized by trilateration.

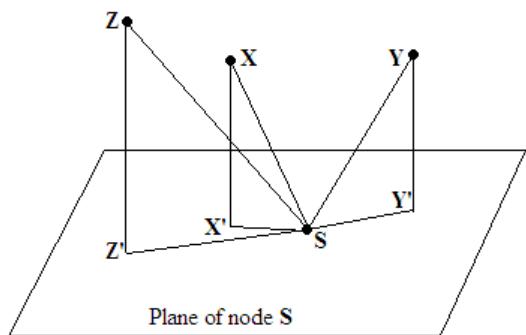


Fig. 3 Projection of reference nodes X, Y and Z to the plane of node S as X', Y' and Z' [14]

Paper [16] introduced underwater positioning system (UPS) scheme. It is a silent positioning scheme that does not require time synchronization among nodes. Four reference nodes including one deployed underwater are used. Time difference of arrival from reference nodes is used for range measurement by sensor nodes. There exists infeasible region in coverage area that contains some nodes which cannot be uniquely localized even if they are close to reference nodes. An extended version of UPS called wide coverage positioning (WPS) scheme is explored in [17]. Five reference nodes are used in WPS to avoid the problem of infeasible region in UPS. Beaconing from fifth reference node is used only when node cannot be uniquely localized by four reference nodes to avoid extra latency and communication overheads. Performance of WPS is worsted than UPS but it achieves unique localization with high probability.

Dive and Rise (DNR) approach is proposed in [8]. Dive and Rise beacons are used which learn their coordinates using GPS when floating on sea surface and then dive in sea to a certain depth and rise again. During this, message containing their location and time are broadcasted to the sensor nodes. Sensor nodes passively listen to DNR message beacons and calculate their location after getting three or more messages. It is a silent positioning scheme and uses TOA for distance measurement. A simple mobility model is used for taken into account the node mobility.

Multistage localization using mobile beacon (PL) is proposed in paper [9]. Here DNR scheme is integrated with iterative localization. DNR beacons dive only to a small depth rather than to cover whole monitoring area in this scheme. A node localized by mobile beacons becomes new anchor node and helps to localize other nodes if it lies below maximum dive depth of mobile beacons. Meandering current mobility (MCM) model is used to consider node mobility [19].

A three dimensional underwater localization (3DUL) algorithm is explored in [6]. Localization process is divided into two phases: 1. ranging and 2. projection and dynamic trilateration. During ranging, estimated sound speed and two ways message are used for distance measurement between sensor node and three neighboring anchor nodes. During 2nd phase, three anchor nodes are projected to plane of to be localizing node. If virtual anchor plane is robust, then trilateration is used to find location. Iterative localization is used to cover large area. Error propagation is avoided by using robustness condition for virtual plane.

IV. RANGE-FREE LOCALIZATION SCHEMES

Range free schemes do not use range or bearing information i.e. TOA, TDOA, RSSI is not used for localization in these schemes. These are simple techniques and provide coarse-grained location estimation for underwater nodes.

An area localization scheme (ALS) proposed in [7] estimates node's location in a certain area rather than exact location. Each reference node sends acoustic signals at different power level. So area is divided in smaller region

based on different power level of reference nodes. Spherical propagation model is used for acoustic signals. Sensor nodes record the minimum power level received for each reference node and send this information to a central server. Central server find the region in which sensor node reside based on that information. Granularity of the scheme is determined by number of power level used by the reference nodes. Main limitations of this scheme are: 1. It is centralized. 2. Coverage is determined by communication range of reference nodes and 3. It does not provide exact position coordinates.

In paper [12], a localization scheme using directional beacons (UDB) is provided. An AUV with directional antenna moves over a predefined route and sends directional signals at some angle toward sensor nodes as shown in Fig. 4.

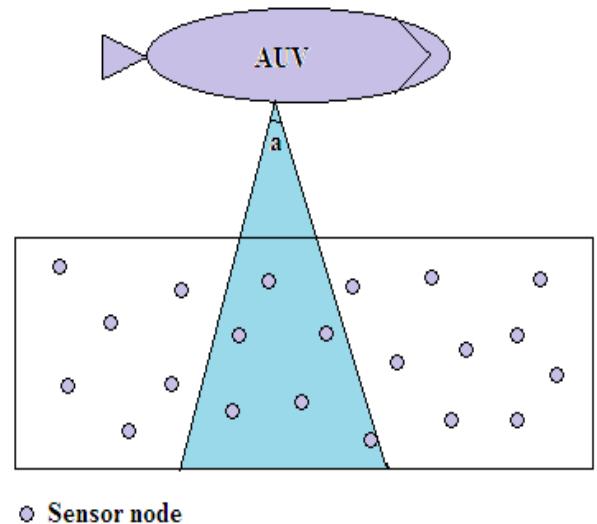


Fig. 4 AUV sending Directional Beacons [12]

Sensor nodes passively listen these signals and localize themselves. It is an energy efficient technique because sensor nodes are only receiving the mobile beacons. Time synchronization among nodes is not required. Sensor nodes are assumed static and coordinates of AUV at two time instance are required for finding position of nodes. Boundary of monitoring area should be known at deployment time for designing AUV route.

UDB is extended to 3D underwater network by Localization with Directional Beacon (LDB) scheme in [13]. LDB is a distributed approach which can be applied to both denser and sparse 3D UWSNs. An AUV mounted with directional transceiver moves over 3D deployment area and sends directional beacons toward sensor nodes. First-heard beacon point and last-heard beacon point are used by sensor nodes to find their coordinates. Work of UDB is extended to 3D network by deploying nodes at different depth and nodes are anchored to ocean floor to prevent them from moving. It is silent positioning and energy efficient scheme. Localization error is upper-bounded.

TABLE I COMPARISON OF LOCALIZATION SCHEMES

Scheme	Range based/Range free	Range Measurement Using	Time Synchronization Required	Silent Positioning	Node Mobility Considered	Iterative Localization Used
DNR	range based	TOA	yes	yes	yes	no
PL	range based	TOA	yes	yes	yes	yes
LSL	range based	TOA	yes	yes	yes	yes
AFLA	range based	TOA	yes	no	yes	no
LSLS	range based	TDOA	no	yes	no	yes
USP	range based	TOA	yes	yes	no	yes
3DUL	range based	two way message exchange	no	no	yes	yes
UPS	range based	TDOA	no	yes	no	no
WPS	range based	TDOA	no	yes	no	no
UDB	range free	N/A	no	yes	no	no
LDB	range free	N/A	no	yes	no	no
ALS	range free	N/A	no	yes	no	no

V. COMPARISON OF LOCALIZATION SCHEMES

Comparison of different localization schemes discussed in this paper is shown in Table II. These are compared on the basis of time synchronization, node mobility, range measurement etc. Nodes should be synchronized if TOA is used for range measurement. Silent positioning schemes are useful in minimizing communication overheads because sensor nodes only receive data and not transmit any data for localization. Transmission consumes more energy rather than receiving. To maximize coverage, recursive localization is useful. If localization of nodes is needed only for routing protocol, then any of range-free schemes can be used. A localization scheme is chosen according to the need of the application. A performance based comparison of DNR, PL and LSL schemes is done in paper [18] using simulation.

VI. CONCLUSION

Localization of nodes in UWSN is a challenging task and it is necessary for data tagging, for routing protocols etc. This paper presented a survey of different localization schemes that is applicable to underwater scenario. These schemes are classified into two categories: range-based schemes and range-free-schemes. Localization schemes of each category are discussed. A number of challenges faced during localization are also presented. At last, localization schemes are compared. A localization scheme should have large coverage, low communication overheads, high accuracy and low deployment cost. A localization scheme is chosen according to the requirement of the application.

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