Project Report (Fall 2021)
(CSI 5148 Wireless Ad Hoc Networking)

Topic - Localization Protocols For Wireless Sensor Networks

Group Number - 18

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1. Abstract

Recently, the underwater wireless sensor network is used in many applications such as military, scientific research, environmental research, etc. For underwater wireless sensor networks (UWSN), the nodes are deployed in a specific region where they collect information and send them to a sink node, thus it is very important to determine the location of every sensor in a sensor network and this process of locating nodes in a network is known as localization. There are many localization protocols for the terrestrial environment but in the case of UWSN; designing and developing localization protocol is harder due to the limiting nature of the communication medium, such as limited bandwidth, high bit error rates, and long propagation delays.

This report will focus on the comparative analysis of the localization-based routing protocols for UWSN based on different criteria, which can be analyzed and considered as a reference to construct a reliable localization protocol for underwater wireless sensor networks. This report covers the introduction of UWSN, the classification of various localization protocols, the basic design of the surveyed algorithms, a brief description of the mode of operations of each algorithm is presented along with its strengths and weaknesses.

2. Introduction

- The majority of the earth's surface is covered by water. UWSN provides promising solutions to explore the underwater environment, in recent years is been used for many applications such as military, scientific research, oil drilling, seismic activity detection, environmental study, etc. There are three main kinds of nodes in underwater wireless sensor networks **Anchor Nodes**, **Unknown Nodes**, **Reference Nodes**. Unknown nodes are used to sense the environmental data, Anchor nodes are used to localize the unknown nodes, the anchor nodes know their location beforehand using the GPS. Reference nodes consist of localized unknown nodes and initial anchor nodes. There are many localization protocols for the terrestrial wireless sensor networks, it is easier to design as there is no constraint of limited energy, low bandwidth, propagation delays, etc, but designing and developing localization protocols for underwater wireless sensor network poses many challenges.

- There are three kinds of waves through which the nodes communicate, radio waves, optical waves, and acoustic waves. Although optical waves provide a faster transmission rate over short distances it faces attenuation underwater. The radio waves and optical waves suffer attenuation underwater and cannot be propagated over longer distances thus the acoustic waves are used in the underwater communication between the nodes. The acoustic waves use adiabatic vibrations to propagate information underwater. Although acoustic waves traverse over a longer distance the speed with which it travels is slower and thus leads to propagation delay between the sensor nodes.

- The sensor nodes in the UWSN collect the required information from the deployed region and send it to a sink node that is located offshore. The communication between the sensor nodes and the sink node is done with the help of acoustic signals. When the sensor nodes collect information and send it to the sink node the location information of each sensor node must also be sent with the collected information, data is meaningful only when it can be referenced to a geographic location, for example, if the sensor network is used for detecting tsunami in a particular region the location from where the nodes are detecting the seismic activity is of utmost importance. When the sensor nodes are manually d[8]eployed their location is known beforehand, but due to the harsh underwater environment in the case of UWSN the nodes are deployed randomly in water and thus the sensor nodes do not know their location. In addition to random deployment, the nodes get drifted away due to water currents also the acoustic waves cause propagation delays thus making it really challenging to design a localization protocol. The GPS technology uses radio waves and thus cannot penetrate more than a few meters deep into water thus we can say that these systems are useless for underwater localization

- Keeping in mind the importance of localization, many protocols are designed. These protocols can be categorized based on different criteria such as mobility (static nodes, mobile nodes), computational model (centralized or distributed), medium of communication (acoustic, optical or magnetic induction), underlying technique (range-based localization, range-free localization), etc.

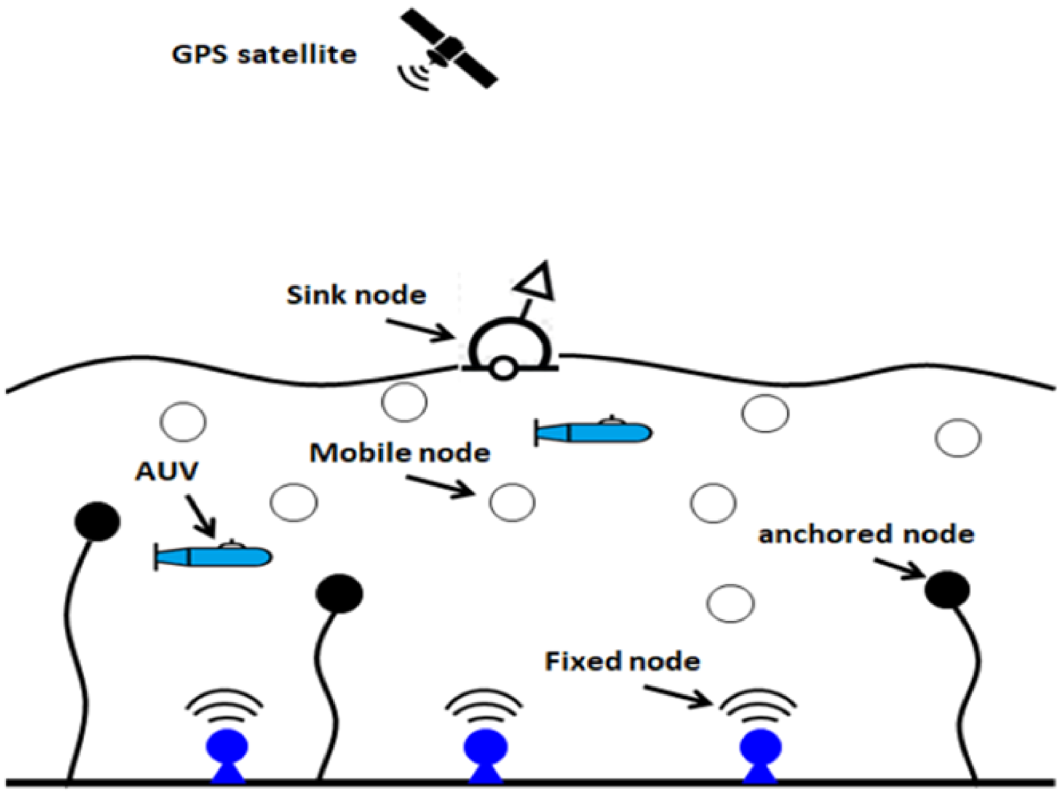

Figure 1: Architecture of Underwater Wireless Sensor Networks.[1]

- The figure depicts the general architecture of UWSN. The sensor nodes are localized using the reference nodes, reference nodes are near the water surface and thus their position can be obtained from the GPS. Moreover fixed anchor nodes and AUVs can be used as reference nodes.AUVs surface at specific intervals to obtain their location estimates and which can be used by the unknown nodes to determine their location.

2. Applications

- Traditional monitoring methods are expensive and complicated [2], These utilize individual and disconnected equipment to collect data from their surrounding environments whereas the UWSN provides simple as well as inexpensive ways to explore the underwater environment.
- The conventional large monitoring equipment is replaced by small and affordable sensors. -
- Some of the applications of UWSN include:

- Oil Drilling.
- Aquaculture.
- Pollution control.
- Climate monitoring
- Prediction and detection of seismic activities.
- Scientific research.
- Military and defence.
- Water Quality Monitoring
- Spill Damage Assesment

4. Performance Objectives

- While designing localization protocols for underwater wireless sensor networks, these objectives should be considered.

Accuracy

- A minimum accuracy threshold for detecting the location of nodes must be achieved. In some applications such as in the case of the military where the target is being tracked high accuracy of nodes localization is required whereas in the case of pollution monitoring less accurate localization calculations are sufficed.

Localization Coverage

- As we know the information sent by a node in a network is only meaningful if the node's location can also be referenced. Localization coverage refers to the number of unknown nodes that a positioning scheme can localize on average. Higher localization coverage leads to a robust system as there is more location information about the nodes which leads to better decision making.

Convergence Time

- The time taken by the protocol to determine the location of nodes must be less, as the nodes are continuously moving around with the current drifts and thus if a protocol takes more time to determine the location it might not be useful.

Energy Consumption

- The nodes in UWSN have a limited supply of energy, the batteries associated with these nodes cannot be changed due to harsh environments and thus the localization protocols must use the least amount of energy possible.

Communication Overhead -

- The communication overhead by the localization protocol should be low, otherwise, it may lead to contention and collisions which in turn causes less accuracy, low convergence, and higher energy consumption.

5. Evaluation Metrics

- When the localization protocol is analyzed there are certain metrics that should be considered for us to decide whether the protocol is good or not. Here are the few metrics that are considered while comparing the performance of the protocols.

Ranging Methods

- Many range-based schemes such as Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) [4], [5], and Received Signal Strength Indicator (RSSI) are used by the ranged based localization protocols each of these schemes offers different levels of ranging accuracy and have different system requirements. For instance, TDoA can achieve better-ranging accuracy as compared to RSSI, however, the range-based protocols require time synchronization which is hard to achieve underwater.[6]

Time Synchronization

- Range-based protocols rely on strict time synchronization between the sender and the receiver, any error in synchronization results in location estimation errors.

Centralized vs Distributed Design

- In centralized design, the sensor nodes send all the information to a central node known as a sink node and it is the responsibility of the sink node to locate all the sensor nodes in a network. Whereas in the distributed approach the localization algorithms are performed by every node individually.

Estimation Based vs Prediction Based.

- Estimation-based protocols use current measurements to determine the location at the current time instant whereas prediction-based algorithms use the past and current measurements to determine the location in the future time instant.[8]

Mobility Consideration

- The nodes' mobility must be considered by the localization protocols to achieve accurate location estimation of sensor nodes. The sensor nodes in a UWSN are continuously drifted by the water currents and if this mobility is not considered then the location estimation will be inaccurate.

Number of Reference nodes

- The reference nodes are used to determine the information about the location of unknown nodes. The number of reference nodes must be increased for a larger network to improve the convergence time and accuracy

Communication Paradigm

- There are two kinds of communication paradigms, active and passive. In the case of the passive communication paradigm, the unknown node only listens to the transmissions from their neighbouring nodes and does not transmit themselves whereas in the case of the active communication paradigm the unknown nodes participate in the localization process by transmitting.[8]

6. Challenges

- Challenges faced can be divided into the following categories

Challenges due to the node's mobility

- Constant movement due to water currents.

Challenges due to the underwater medium.

- Lack of availability of satellite positioning system.
- Doppler's shift

Challenges due to the acoustic wave.

- Slow and variable speed of sound waves.
- Limited Bandwidth
- Multipath Affect
- High bit rate Errors

7. Protocols Based on Computational Design

-These protocols are classified on basis of determining the location of unknown or unlocalized nodes. [10]

- They can be classified into two categories based on their computational design, namely :

1) Centralized Protocols 2) Distributed Protocols

7.1 Centralized Protocols

- These are the protocols that determine the location of unknown nodes at a centralized location like a sink node which will carry out a location estimation procedure based on gathered information by employing some localization algorithm [15]. Further centralized schemes are divided into two categories based on mobility :-

7.1.1 Centralized localization schemes with mobility consideration.

- This includes two stage localization scheme for partitioned UWSNs [11]. Using trilateration every node for position estimation hosts three non-collinearly positioned antennae. Here nodes are divided into n tiers, where tiers are set of nodes in the communication range of previous tier nodes (tier n-1).
- Only a single reference node is present in tier 0, which has already known coordinates. Stage 1 is initiated when the reference node transmits a beacon and sets up a timer for receiving an acknowledgment (ACK). When the beacon is received, each tier 1 node calculates its distance from the sender and transmits a packet with a transmission range higher than the calculated distance as a response.
- Here packet serves two purposes, firstly for the sender in the previous tier i.e. the reference node acts as acknowledgment. Secondly, it acts as a beacon for next tier nodes i.e. tier 2.
- On getting acknowledgment, the positions of the sender relative to itself is estimated and saved in its table of relative location by reference node using trilateration. This table of relative locations is maintained by every node and it is passed to the reference node after a fixed time constraint.
- The same set of steps are repeated on the reception of the beacon or acknowledgment by nodes in any tier.

- Figure 4 shows that after multiple transmissions the table of relative locations arrives at tier 0 (reference node) from higher tier nodes. Then by using this received tables, the tier 0 node can locate the relative positions of all the node with respect to itself.
- Finally in stage 2, with respect to the relative position to the reference node and the absolute position of the reference node at time instance t, the absolute positions of all the nodes are estimated.

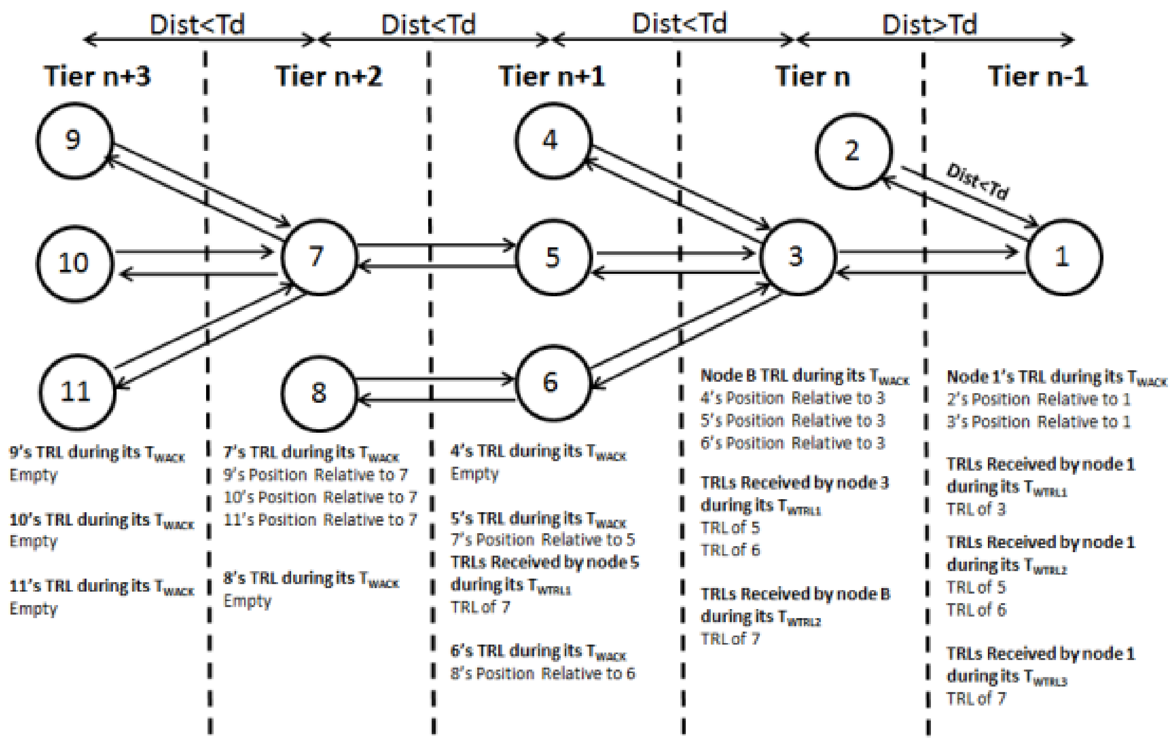

Figure 2 : Propagation of beacon and Tables of Relative location [11]

Advantages :-

i) This protocol initiates a partition handling mechanism which allows partitioned nodes to request beacons proactively after a fixed time constraint.

ii) Its ability to handle partitioned networks is superior.

Disadvantages :-

i) In a dense networks, the partition handling mechanism seeks more number of responses which leads to high communication overhead.

ii) Also, energy consumption increases in handling the higher number of responses.

7.1.2 Centralized localization schemes without mobility consideration

- Here RSSI based localization method is used for energy harvesting wireless underwater sensor networks [12].
- This protocol enables the low-energy nodes to collect ambient energy, so that nodes can get active again when a sufficient amount of energy is collected. This framework allows us to deal with the limited energy constraint (figure 3).
- For estimating the location, active nodes calculate the distances based on RSS subject to the impairments of the optical underwater channel. For estimating RSS distance same process is followed by computing block kernel matrices.
- Also, for mitigating the error rate in the estimation of shortest paths in the block kernel matrices various matrix completion procedure is employed. When block kernel matrices is completed, a closed-form of location estimation procedure is employed for localizing the nodes.

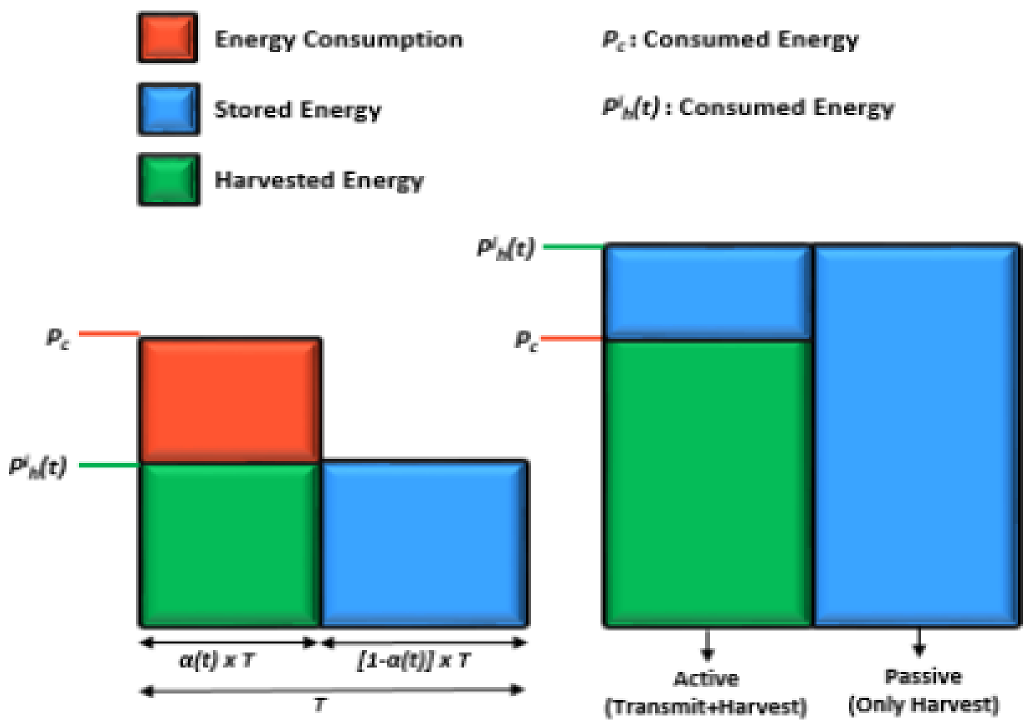

Figure 3 : Illustration of time slotted operation of sensor nodes [12]

Advantages :-

i) This scheme includes energy harvesting that makes it robust.

ii) Network also achieves a higher lifetime because of energy harvesting.

Disadvantages :-

i) For localizability of nodes it does not consider the effect of node mobility which eventually results in high erroneous estimations while using light as a medium of communication.

7.2 Distributed Protocols

- In distributed protocols, every unlocalized node individually collects the information of location and conducts location estimation procedures separately [15]. Further distributed schemes are divided into two categories based on mobility :-

7.2.1 Distributed localization schemes with mobility consideration.

- Using [13], we are stating two-stage cluster-based distributed localization scheme with the capability of handling partition for mobile UWSNs.
- In stage one, throughput network a beacon is passed. Using trilateration all the nodes localize themselves upon receiving the beacon.
- However, beacon may not be received by certain partitioned nodes. An iterative stage 2 is initiated by these partitioned nodes, in which after a certain threshold time these partitioned nodes transmit a beacon request with higher transmission power.
- Reference node responds by transmitting a beacon whenever a beacon request is received. This beacon should be received by the requester within a certain time threshold. Otherwise, when the time threshold is over and a beacon is not received, then the clusterheads doubles the transmission power and send a localization request again, and wait for a beacon. (which are selected among the partitioned nodes based on random numbers included in the beacon request sent in the previous iteration)
- Here the clusterheads are selected from partitioned nodes based on random numbers present in the beacon request sent in the preceding iteration.
- The above process is repeated until a beacon is received or the maximum repetition limit is reached.

Advantages :-

i) The biggest advantage of this protocol is its clustering strategy, it reduces the energy consumption to a great extend as only clusterheads are allowed to request beacons on behalf of the entire cluster.

ii) Also, the clustering strategy mitigates contention.

iii) Clusters increases in size because of elevating the number of iterations, which results in lesser clusterheads and lower traffic.

iv) Protocol also employs a retransmission strategy to control and reduce the number of transmissions.

Disadvantages :-

i) However, if retransmission strategy is employed properly then number of transmissions will increase and protocol may have to deal with overhead.

7.2.2 Distributed localization schemes without mobility consideration

- Here we are stating a Two Phase Time Synchronization Free Localization Algorithm (TP-TSFLA) using mobile beacons as proposed in [14].

- The nodes in the network are of two types:

A) Mobile beacon nodes whose locations are known.

B) Static sensor nodes with unknown locations.

- Here the figure 4 depicts the workflow of the protocol. This scheme is divided in two phases.

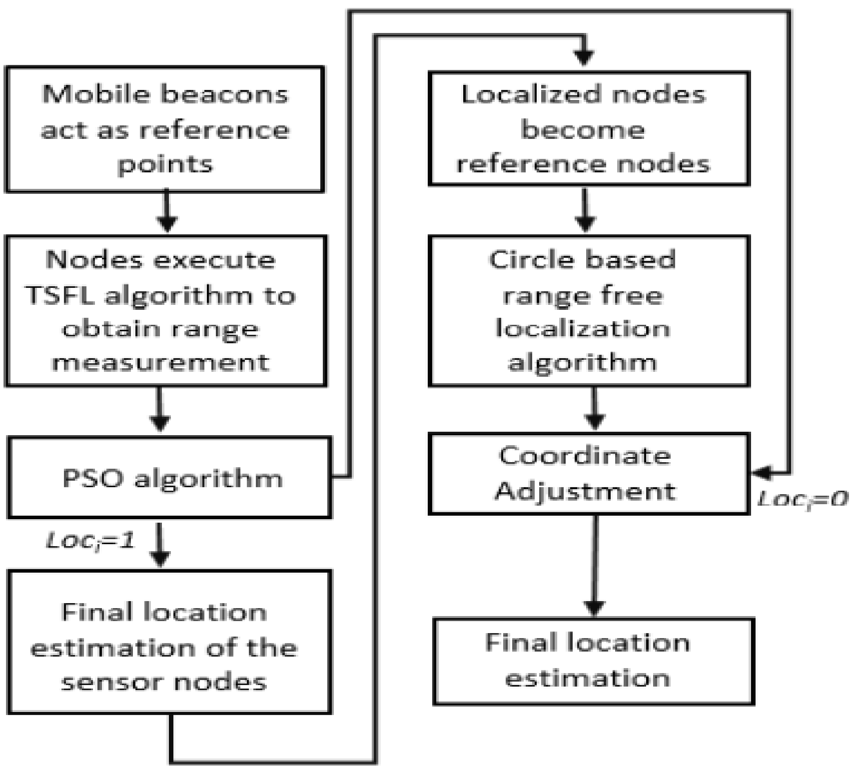

Figure 4 : TP-TSFLA work flow [15]

- In the first phase, mobile beacons act as a reference point. Then, the ranges measurements between the unknown sensor nodes and the mobile beacon nodes are obtained by executing Time Synchronization Free Localization (TSFL). After that, Particle Swarm Optimization (PSO) is employed to estimate the location of the sensor nodes with known range.
- However, some of the nodes that did not receive beacon during phase 1 remain unlocalized.
- The second phase is initiated by these unlocalized nodes by transmitting beacon requests. Now, the nodes that are already localized nodes act as reference nodes and send back their coordinate information as a response to the requests.
- By using this received response, every unknown node localizes itself proactively by employing Circle based Range Free Localization Algorithm (CRFLA).
- Then coordinate adjustment scheme is used to improve the accuracy of CRFLA based location estimation.

Advantages :-

i) To carry out localization the proposed protocol does not need time synchronization. This makes it a more practical solution because it is difficult to achieve time synchronization in underwater.

ii) The precision of the method is improved because of the employed coordinate adjustment scheme.

Disadvantages :-

i) The scheme is prone to errors in localization.

8. Protocols Based on Node Mobility

Localization algorithms are mainly classified into three categories based on sensor node's mobility :

1) Stationary localization algorithms
2) Mobile localization algorithms
3) Hybrid localization algorithms

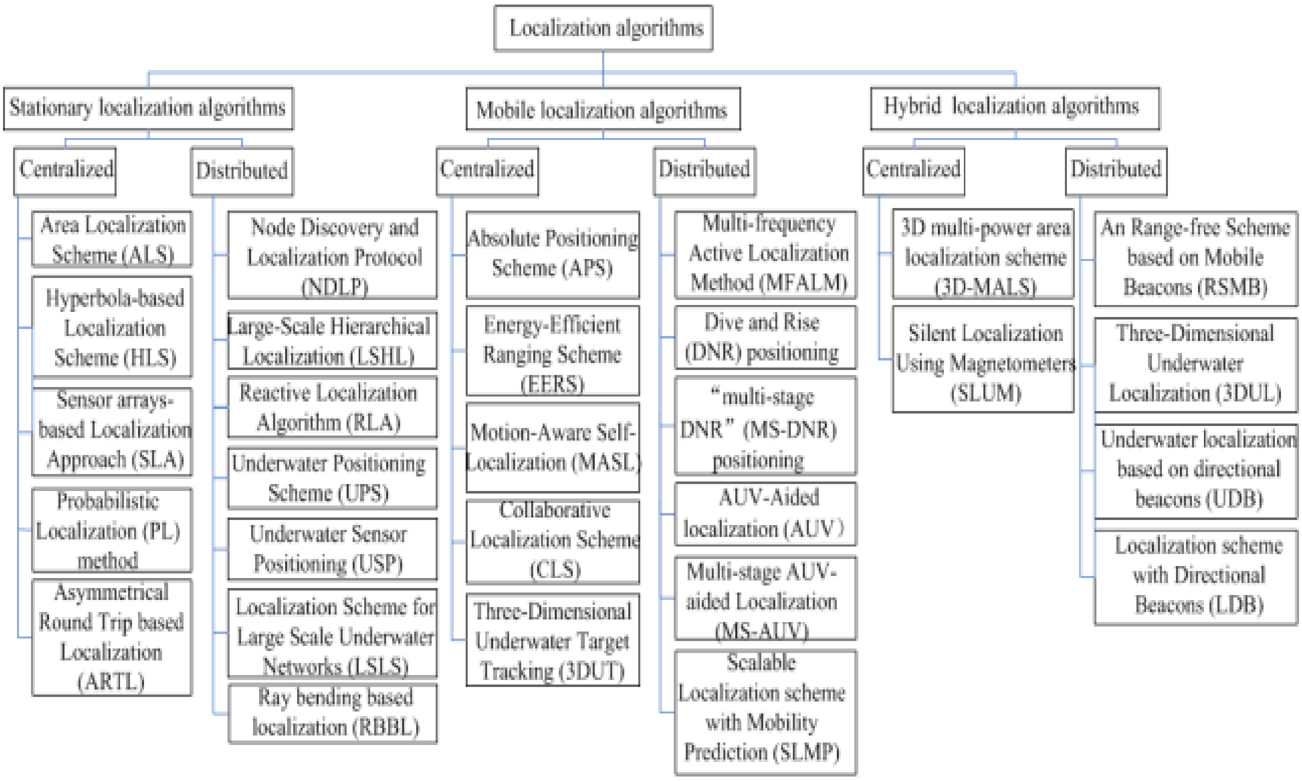

Figure 5 : Classification of localization algorithms [16]

8.1 Stationary localization algorithms :

- All sensor nodes are static in stationary localization algorithms and are attached to ocean floor units or surface buoys which have fixed locations.

There are two type of stationary localization algorithms :

1) Centralized Localization Algorithms
1) Distributed Localization Algorithms

8.1.1 Centralized Localization Algorithms :

- Here the location of unknown nodes is determined at a centralized location like sink node.

- There are five different schemes of Centralized Localization Algorithms :

8.1.1.1 Area Localization Scheme :

- Area Localization Scheme estimates the location of every unknown node within a particular area rather than locating the exact position. The main task of anchor nodes is to send out signals with different levels of power to localize nodes that are unknown.

- Unknown nodes listen to the signals and record the anchor nodes' IDs and together with this collected data, the recorded information is sent to the sink node. The Sink node is assumed to know the positions of all anchor nodes and their transmitted power levels. Therefore, sink nodes can localize unknown nodes with proper signal propagation algorithms.

Advantages :

1) It is Range free.
2) No synchronization requirement.
3) Complex calculations are handled by the sink node instead of unknown nodes.
4) Reduced energy consumption of unknown nodes and extends the lifetime of the network

Disadvantages :

1) Not convenient for accurate and instant location information.
2) It incurs high communication overhead and energy consumption.
3) After deploying the network, it would not be possible to change the positions of anchor nodes.

8.1.1.2 Hyperbola-Based Localization Scheme (HLS)

- This proposed scheme utilizes the hyperbola-based approach for localization and a normal distribution for estimation error modeling and calibration. When any unknown node detects one event, it will report the event to anchor nodes immediately.

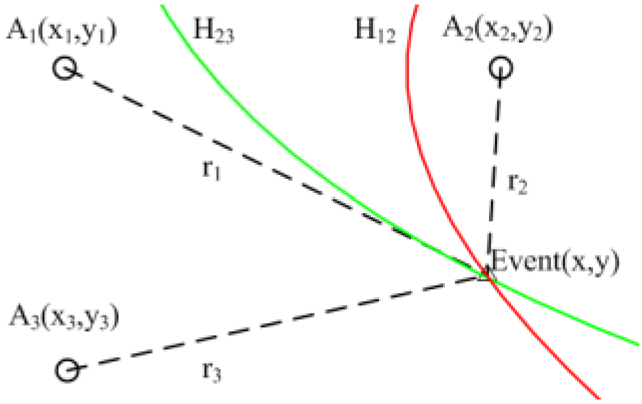

Figure 6 : Hyperbola-Based Localization Scheme [16]

Anchor nodes (A1 & A2) will receive event at time (t1 & t2). Unknown node is localized on a hyperbola N12 based on the property of hyperbola. The intersection of any two curves provides an estimation position of an unknown node.

Advantages :

1) HLS is more robust against distance measurement error and can also localize more unknown nodes
2) Localization accuracy of HLS is better than that of the least squares algorithm.

Disadvantages :

1) Sensor nodes are required to send long-range signals (around 1,000 meters).
2) Excessive energy is consumed.
3) Anchor nodes need to be stationary and hence HLS is not extendable to mobile UWSNs.

8.1.1.3 Sensor Arrays-Based Localization Approach (SLA)

- Each sensor array is equipped with an array of sensor nodes that are attached to the sensor array through wired connections. Every target that is waiting to be localized periodically emits a narrow-band acoustic signal. For each sensor array, using the negative log-likelihood function, sensor nodes which have received the signal can obtain the target positions and signal amplitudes. The maximum likelihood estimate of the target location is obtained based on the global likelihood function, that is the sum of the local likelihood function [17].

Advantages :

1) Does not need distance measurement and time synchronization
2) Computation overhead of sensor nodes and targets are low

Disadvantages :

1) Communication overhead and energy consumption are high as all the local likelihood functions are forwarded to a fusion center.

2) Local wired and global wireless network architecture is not feasible for large scale UWSNs.

8.1.1.4 Probabilistic Localization Method (PLM)

- PLM is proposed to improve localization accuracy. It consists of two steps. In the first step, every two neighbouring anchor nodes calculate locations of unknown nodes using a hyperbola-based or circle-based approach. The second step is to determine the final locations of unknown nodes by using the probability distribution of distance measurement error.

Advantages :

1) Localization coverage and accuracy can be improved by utilizing more anchor nodes.

Disadvantages :

1) Computation complexity and energy consumption increase greatly.

8.1.1.5 Asymmetrical Round Trip Based Localization (ARTL) Algorithm

- ARTL assumes that anchor nodes can receive their own packets while unknown nodes cannot. The basic ranging scheme is implemented to get distances between anchor nodes and unknown nodes. Based on the time difference of arrival signals, the distance could be calculated. With the collected data information, the calculated distances are sent to the base station which launches the localization task.

Advantages :

1) No time synchronization is required and also no complex computations are handled by anchor nodes and unknown nodes.
2) ARTL does not require unknown nodes to immediately reply after receiving the ranging broadcast.
3) ARTL is easy to extend.

Disadvantages :

1) Long localization time.
2) Much energy is consumed to send the calculated distances to the base station.

8.1.2 Distributed Localization Algorithms :

- Here the location of unknown nodes is determined at a distributed locations.

- There are seven different schemes of distributed Localization Algorithms for hybrid localization :

8.1.2.1 Node Discovery and Localization Protocol (NDLP)

- Node Discovery and Localization Protocol (NDLP) manages sub-sea localization. NDLP starts with one seed node (primary) with a known position. The primary seed node is capable of determining the relative positions of neighbouring nodes. A second seed node is then chosen by the primary seed node. Second node is the most distant node within the communication range of the primary node. A third seed node is chosen from those nodes that lie in both communication ranges of primary seed node and secondary seed node, and has the maximum summation distance from both primary and secondary nodes. In order to localize the nodes in the cross-hatched region, a fourth seed node is selected based on four algorithms, Farthest/Farthest Algorithm, Farthest/Nearest Algorithm, Nearest/Farthest Algorithm, and Nearest/Nearest Algorithm.

Advantages :

1) NDLP is an anchor-free and GPS-less algorithm
2) Large scale of unknown nodes can be localized

Disadvantages :

1) Large communication overhead
2) Energy consumption of node discovery is high
3) Unknown nodes' relative coordinates calculated based on the seed nodes' positions are not accurate.
4) Repeating the node discovery each time the topology changes is unaffordable

8.1.2.2 Large-Scale Hierarchical Localization (LSHL) approach :

- Surface buoys drift on the water surface and get their positions from GPS. To get their absolute positions, anchor nodes can directly communicate with the surface buoys. To localize themselves, unknown nodes cannot directly communicate with the surface buoys but can communicate with anchor nodes.

8.1.2.3 Reactive Localization Algorithm (RLA) :

- RLA localizes a node that detects an event rather than localizing every single node in the network. Once a sensor node detects an event, RLA start working in two steps. The first is to find anchor nodes. The sensor node first broadcasts a hello message with its ID and energy level to its neighbours and the second step : reactive localization of the sensor node. Once the selected anchor nodes receive a localization request message, they reply with their position information. The sensor node hence localizes itself by quadrilateration.

8.1.2.4 Underwater Positioning Scheme (UPS) :

- UPS has two steps. The first one is to detect the time differences of arrival signals and then the time differences are transformed into range differences. Second step consists of performing trilateration to localize unknown nodes.

Advantages :

1) UPS requires no time synchronization and has low computation overhead.
2) UPS has low localization error.

Disadvantages :

1) Sensor nodes outside the four anchor nodes' communication range cannot be localized
2) Few anchor nodes are needed to perform 3D localization

8.1.2.5 Underwater Sensor Positioning (USP) :

- In the USP scheme, nodes that are unknown get their depth information by pressure sensors. To transform the 3D underwater positioning problem into its 2D counterpart via the projection technique, the depth information is used.

Advantages :

1) Low storage and computation requirements
2) Installing pressure sensors increases energy consumption per unknown node.

8.1.2.6 Localization Scheme for Large Scale underwater networks (LSLS) :

- LSLS is a hierarchical localization approach that includes three phases: sea surface anchor localization, iterative localization, and the complementary phase. In the first phase, three surface anchor nodes send their beacon messages sequentially to calculate the range difference as described in UPS. After that unknown nodes are localized as described in USP. During the second phase, certain localized nodes are selected to serve as reference nodes. More unknown nodes are localized as described in the first phase and If a node fails to be localized in either of two phases, it can initiate a location request in the third phase.

Advantages :

1) LSLS can localize a large-scale UWSN with short-range acoustic communication compared with UPS.

2) LSLS localize more unknown nodes than USP does.

Disadvantages :

1) More energy and communication overhead are consumed.

8.1.2.7 Ray Bending based Localization (RBL) :

- Ray Bending based Localization (RBL) method that accounts for ray bending in water. With the assumption of straight line trajectory and constant velocity, the constant range interval surface is spherical. For the ray tracing model [23], the constant range interval surface is not spherical but it retains axial symmetry about the longitudinal axis containing anchor node, since velocity varies only with depth.

8.2 Mobile localization algorithms :

- In mobile localization algorithms, all sensor nodes are mobile. Nodes can freely drift with water currents or use propelled equipment, For Example : Autonomous Underwater Vehicle (AUV), to control their movements.

There are two type of stationary localization algorithms :

1) Centralized Localization Algorithms
2) Distributed Localization Algorithms

8.2.1 Centralized Localization Algorithms :

There are five different schemes of Centralized Localization Algorithms for hybrid localization :

8.2.1.1 Absolute Positioning Scheme (APS)

- Absolute Positioning Scheme (APS) is proposed to localize an AUV and this AUV transmits an interrogation pulse at a fixed rate. The signals received at the surface consist of a direct signal from the AUV and a reply from every transponder. The time difference of arrivals along with depth measurements from an onboard pressure sensor are used to localize the AUV.

8.2.1.2 Energy-Efficient Ranging Scheme (EERS)

- In order to localize a swarm of sensor-equipped drifters that float freely with ocean currents, an Energy-Efficient Ranging Scheme (EERS) is used. Firstly the range can be deduced from the one-way time of exchange message arrival measurement. This step is called Sufficient Distance Map Estimation (SDME). SDME consists of a synchronization step (SDME-S), followed by a distance estimation step (SDME-D). SDME-S is a synchronization-data collection algorithm to achieve time synchronization. SDME-D is a two step distance estimation process. During distance estimation, not all the nodes need to broadcast localization message. Therefore, SDME-D first selects the subset nodes that need to broadcast localization message. The localization based on EERS is an anchor-free self-localization scheme, which can be extended for large scale UWSNs. [16]

8.2.1.3 Motion-Aware Self-Localization (MASL) scheme

- In this, nodes first perform ranging with their neighbours to get all the distance estimates in the localization epoch.After that, all distance estimates are sent to a central station and processed offline. MASL is a centralised anchor-free localization algorithm, which reduces unknown nodes computational burden and can be used to localize large scale UWSNs.

8.2.1.4 Collaborative Localization Scheme (CLS)

- Nodes collaborate to determine their positions autonomously without using long range transponders on surface buoys or ships in CLS. Network is deployed at the starting of the surface, sensor nodes use buoyancy control to descend deeper into ocean. They travel back to surface when maximum depth is reached. Their positions in the other two dimensions change continuously due to the motion induced by currents while the nodes are descending. Initially, GPS can be used to track the nodes at the surface.

Advantages :

1) CLS is anchor-free and cost effective self-localization strategy.
2) Does not require prior node planning.

Disadvantages :

1) Architectural dependence
2) Time synchronization is required.

8.2.1.5 Three-Dimensional Underwater Target Tracking (3DUT)

- This works in 2 phases, where in the first phase, Passive Listening, sensor nodes listen to the underwater environment for potential targets. During the second phase of the algorithm, Active Ranging, is to localize the target. The target is assumed to be a point target so that the echoes are radiated isotropically. Distance to the target is calculated once the echo is received by the projector and transmits to the sink node. Sink node uses trilateration to localize the target. The location and the calculated velocity of the target are then exploited to achieve tracking.

8.2.2 Distributed Localization Algorithms :

There are six different schemes of Centralized Localization Algorithms for hybrid localization :

8.2.2.1 Multi-frequency Active Localization Method base on TDoA (MFALM) :

- There are three types of nodes, that are buoy nodes, relay nodes and ordinary nodes. After the network is deployed, buoy nodes firstly localize themselves using GPS and with low-frequency acoustic signals it periodically broadcasts localization information. Relay nodes communicate with each other with low-frequency acoustic signals to divide the network into multiple localization domains and then calculate the value of max hops for each domain. Ordinary nodes which detect event open low-frequency signal receiving devices to receive localization information from buoy nodes and localize themselves.

8.2.2.2 Dive and Rise (DNR) positioning scheme :

- DNR anchor nodes are used to replace the ones which are static. Every DNR anchor node is equipped with GPS. While sinking and rising, they broadcast their locations. By passively listening to DNR anchor nodes' messages, unknown nodes are localized. Unknown nodes estimate their coordinates after hearing from several anchor nodes.

Advantages :

1) Reduces communication overhead and energy consumption

2) Unknown nodes spend energy only in receiving and processing localization message.

3) Can localize unknown nodes in deep water.

Disadvantages :

1) Anchor nodes diving and rising takes longer time than message propagation.
2) Localization performance heavily depend on frequency of location updates and number of anchor nodes.
3) Higher localization accuracy and less energy consumption and communication overhead.

8.2.2.3 "multi-stage DNR" (MS-DNR) positioning scheme :

- "multi-stage DNR" (MS-DNR) is used to speed up the localization process at cost of less accuracy and more messaging. They start to act as reference nodes, once unknown nodes become localized. Unknown nodes lying out of the communication range of DNR anchor nodes can be localized by the localized unknown nodes.

8.2.2.4 AUV-Aided localization technique :

- UWSN consists of many sensor nodes and one AUV. The sensor nodes are dropped into ocean and move with water currents. The AUV traverses the UWSN periodically following an Archimedean spiral trajectory trajectory which is predefined. Every nodes can communicate (omni-directionally) with the AUV. The AUV can surface to obtain its coordinates by GPS, then dives to a predefined depth and starts exchanging three types of messages with unknown nodes that are wakeup, request and response.

Advantages :

1) Does not assume any fixed infrastructure or time synchronization.
2) 100% localization can be achieved with only 3% localization error.

Disadvantages :

1) Localization technique has high localization delay (about up to 2 hours).

8.2.2.5 Multi-stage AUV-aided Localization (MS-AUV) scheme :

- MS-AUV combines the flexibility of the energy efficiency of the "Silent Localization" and the AUV-aided localization, where unknown nodes passively listen to localization message.

Advantages :

1) Localization process can be completed in less than 10 minutes and can cover more than 95% of the whole network

Disadvantages :

1) MS-DNR, accumulated error is inevitable

8.2.2.6 Scalable Localization scheme with Mobility Prediction (SLMP) :

- Localization in SLMP is performed in a hierarchical way and the whole localization process is divided into two parts that are unknown node localization and anchor node localization. Each node predicts its future mobility pattern according to its past known location information during the localization process.

Advantages :

1) Communication overhead and energy consumption of SLMP are relatively low.

Disadvantages :

1) When Time is short, a relatively high communication overhead is needed.
2) The performance of SLMP heavily depends on the structure of the mobility pattern.

8.3 Hybrid Localization Algorithms :

- Currently, there are some hybrid UWSNs that have been employed where stationary and mobile sensor nodes coexist.

There are two type of hybrid localization algorithms :

1) Centralized Localization Algorithms
2) Distributed Localization Algorithms

8.3.1 Centralized Localization Algorithms :

There are two different schemes of Centralized Localization Algorithms for hybrid localization :

8.3.1.1 3D multi-power area localization scheme (3D-MALS) :

- It is a range-free method based on mobile detachable elevator transceiver (DET) [18,19] and 3D multi-power area localization scheme (3D-MALS) to localize unknown nodes in deep underwater environment. In hybrid UWSNs, a very small amount of surface buoys are placed on the water surface. Each buoy is equipped with a DET, which is mainly composed of a multi-power level acoustic transceiver and an elevator. The elevator helps the DET rise or dive vertically underwater and the transceiver communicates with nodes that are unknown. The DET gets coordinate from its buoy when it moves to water surface, then moves down to broadcast position information at some pre-configured depths.

Advantages :

1) Save energy consumption of unknown nodes.

Disadvantages :

1) Localization accuracy of 3D-MLS is low like that of ALS.

2) Much energy is needed to transmit multi-power level signals.

8.3.1.2 Silent Localization Using Magnetometers (SLUM)

- SLUM silently localize underwater unknown nodes equipped with triaxial magnetometers using a friendly vessel with a known magnetic dipole. Unknown nodes are localized by listening to the messages of the dipole. Magnetometers are used to measure the ferromagnetic field created by the dipole and it is used to localize unknown nodes. Every unknown node is further equipped with an accelerometer and a pressure sensor used for depth estimation and sensor orientation estimation, respectively. The trajectory of the vessel and the locations of unknown nodes are estimated using an Extended Kalman Filter simultaneously (EKF) [20, 21].

8.3.2 Distributed Localization Algorithms :

- There are four different schemes of Centralized Localization Algorithms for hybrid localization :

8.3.2.1 An Range-Free Scheme Based on Mobile Beacons (RSMB)

- A mobile anchor node moves on the sea surface at a constant speed and broadcasts beacons at regular intervals which is called beacon distance. Here, the mobile anchor node follows the random way-point (RWP) model [22], the mobile anchor node moves in a series of straight paths to random destinations.Since the unknown node knows its own depth information, the received beacons can be projected on the plane where it locates. RSMB has two steps where the first step is to select three beacons among the received beacons and the second step is to estimate the position of unknown node.

Advantages :

1) Can estimate its own location independently.

Disadvantages :

1) Localization time and accuracy mainly depend on the beacons’ sending interval

2) High energy is consumed for the anchor node’s movement and the projection technology

3) Cannot localize unknown nodes in deep water.

8.3.2.2 Three-Dimensional Underwater Localization (3DUL)

- There are three buoys floating on the surface and many underwater sensor nodes are deployed at different levels of water (different depths). Also, there are propelled autonomous robots freely floating with water currents. The underwater sensor nodes and the propelled robots are unknown nodes.
- In first phase, unknown nodes estimate the distances to their neighbour buoys by using two-way message exchange techniques and acquire their depth information. During the second phase, the unknown node projects the buoys' locations onto its horizontal level.

Advantages :

1) Does not require time synchronization.

Disadvantages :

1) Very long localization time.

8.3.2.3 Underwater localization based on directional beacons (UDB)

- Underwater localization approach is based on Directional Beacons (UDB) for hybrid UWSNs, where mobile AUV and stationary unknown nodes coexist. The directional beacons are transmitted by an AUV, which moves according to a predefined route navigated by compass. A directional antenna is used on the mobile AUV and the angle of signal is controllable.

Advantages :

1) Range-free localization scheme.

Disadvantages :

1) Localization coverage is limited
2) Not suitable for large scale UWSNs
3) If the AUV sends beacons with too long intervals, many unknown nodes may not be localized.

8.3.2.4 Localization scheme with Directional Beacons (LDB) :

- The depth of a node can be directly measured by a cheap pressure sensor, LDB is designed to determine its 2D position at the fixed depth. When AUV patrols at a fixed depth of water following a straight line and sends beacons continuously, nodes in its communication range can receive a series of beacons.

9. Protocols Based on Underlying Technique.

- Localization schemes generally require some nodes in the network to know its own location. Such nodes whose locations are known are addressed as reference nodes or anchor nodes.
- The localization protocols that use these reference nodes can be classified into two categories [24], namely:

i) range-based schemes (schemes that use a range or bearing information), and

ii) range-free schemes (schemes that do not use a range or bearing information).

9.1 Range-based Protocols

- In range-based protocols the range or measurement information is used, information such as Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and Received Signal Strength Indicator (RSSI) is used to determine the location of a node in the network [24].
- Range-based schemes can be divided into three categories in the context of underwater sensor networks: infrastructure-based schemes, distributed positioning schemes, and schemes that use mobile beacons

9.1.1 Infrastructure based scheme

- Infrastructure-based is also known as the anchor-based scheme, it utilizes GPS technology. Anchor nodes are deployed at a predetermined location on the sea-bed, some nodes that float on the surface which can be located by GPS are also used as anchor nodes.
- The distance is calculated for each node by using multiple anchor nodes and using measurement information. Such schemes are used in real life by the US Navy in which the calculation of the location of sensor nodes of UWSN is done using the least square method

9.1.2 Distributed Positioning Schemes

- In situations where positioning infrastructure is not available (that means anchor-free), the distributed positioning schemes are employed. In these schemes, nodes compute the distances to their one-hop neighbors as they are able to communicate only with them.
- For estimating the location of each sensor node, multilateration techniques are used in

distributed manner, which encompasses techniques like atomic, collaborative, and iterative multilateration.

- Distributed positioning protocols basically have three positioning phases: the distance estimation phase, where nodes find the distances to their neighbors, the position estimation phase, where a least squares approach is used to solve system of linear equations to estimate the position of the node, and lastly a refinement phase, where an iterative algorithm is used to improve the accuracy of the algorithm.
- Various scheme that fall in this category are the NHop Multilateration Scheme [25], the Hop-TERRAIN and Refinement Scheme [26], Ad Hoc Localization System (AHLoS) [27] and Ad Hoc Positioning System (APS) “Distance Propagation” and “Euclidian Propagation” Schemes [28].
- In distributed positioning schemes, RSSI or ToA measurements are used by nodes to find their distances to neighbors. However, ToA based ranging is the preferred option in underwater sensor networks as the mode of communication between nodes is acoustics.

9.1.3 Schemes that use Mobile Beacons / Anchors

-The anchor node in the scheme discussed above has a fixed anchor node. In this scheme the mobile beacons while moving constantly through sensor networks, transmits the beacon packets that contain the information of coordinates of the mobile beacon node currently, the receiving nodes will know that they are somewhere near the beacon node.

-RSSI information from the beacon packets is used for calculating the location estimates. This process continues till many such beacon packets are obtained and then the Bayesian inference is used to estimate the location of the node.

- Here the challenge faced is that sometimes location of the AUVs itself is not known. In such scenarios first one has to determine the location of the AUV and then used it for positioning nodes on the seabed.

-The problem with schemes that uses RSSI information is it has a large variance in reading, other problems include multi path fading, irregular signal propagation patterns and background interference.

9.1.4 Schemes without Anchor/Reference Points

- This category of schemes is different from the earlier three in context that it does not require anchor nodes or beacon signals.
- Alternative such as a central server can be used to model the network as a series of

equations representing proximity constraints between nodes [29]. After that, to estimate the location of every node a sophisticated optimization techniques is used.

9.2 Range Free Protocols

- In Range-free localization schemes the measurement information or range is not used. Thus, to estimate distances to other nodes, it does not use any of above mentioned techniques like ToA, TDoA and AoA, which makes this schemes simple to implement [24].
- Certain schemes that this category includes are the centroid scheme [30], DV-Hop [31] and Density aware Hop-count Localization (DHL) [32].
- Range-free schemes can be generally divided into 2 types : hopcountbased schemes and area-based schemes. Moreover, this schemes only provides a rough estimate of node's location.

9.2.1 Hopcount based Schemes

- In hopcount-based schemes anchor nodes are placed along the boundaries of a square grid or at the corners.
- Once of basic range-free protocols include DV-Hop[31]. Firstly, it appoints distance vector exchange in order get distances, in number of hops, to the anchor nodes for all nodes in network. Here every node communicates only with its neighbors and exchanges updates as well as maintains a table. Average distance for one hop is estimated and propagated as a correction to the whole network, when one node gets the distance to other nodes. On reception of correction, triangulation can be performed by calculating the distance, in meters, in-between the landmarks and an arbitrary node [31].
- This DV-Hop schemes performs good in dense and uniform node distributions. For situations where the node distribution is sparse and non-uniform schemes like Density-aware Hop-count Localization (DHL) [32] have been proposed to improve the accuracy of location estimation.
- The DHL scheme, while computing the average hop distance, considers both the density of a node's neighborhood as well as, the fact that with the increase in path length, errors in distance calculation may also increase.
- It is observed that in networks where anchor nodes are placed at the corners of a square grid, the error-rate is lower in the middle of the region and higher along the boundaries. To

resolve this a Selective Iterative Multilateration (SIM) algorithm [33] is proposed, where it is made sure that initial position estimate of new selected anchor nodes is sufficiently accurate.

9.2.2 Centroid Scheme

- This are the schemes, where anchor nodes are placed to form a rectangular mesh. Also, it requires large amount of anchor nodes to perform well.
- At periodic intervals the beacon signals is send out by anchor nodes with their respective locations. A receiver node deduces proximity to a collection of anchor nodes from the received beacon signals.
- Then, the estimated location of the node is considered be the centroid of the anchor nodes, from which it can receive beacon.
- However, in the context of underwater this scheme is difficult to implement as it needs to set up a rectangular mesh of anchor nodes on the seabed.

9.2.3 Area-based Localization Schemes

- It is not always possible to estimate the exact location of each node, thus in dense and wide networks we may want to find a rough estimate of location of nodes, this scheme are known as area-based localization schemes.
- Two examples of area-based schemes are the Area Localization Scheme (ALS) [34] and Approximate Point in Triangle (APIT) [35] where rather than exact location, an approximate area in which node are present is located.

9.2.3.1 Area Localization Scheme (ALS)

- ALS [34] provides approximation of node’s location in a specific area instead of locating exact coordinates. Here, Anchor nodes transmits beacon signals at varied power levels, the grid is then divided into multiple small areas based on the ranges of the different power levels.
- After that, the lowest power level received from anchor node is measured by sensors and forwarded to the sink for processing along with data. Here, the lowest power level is represented by i th coordinate of the i th anchor node and measured information is represented by n-dimensional coordinates.

9.2.3.2 Approximate Point In Triangle (APIT)

- In APIT [35] scheme, from all detectable anchors that transmits the beacon, node chooses any three anchors and checks that if it is inside the triangular region formed by selected three

anchors. The test used to check this is called as Point-In-Triangle (PIT) test.
- However, this PIT test has a condition that it can be carried only when every node in network is mobile, which is quite infeasible. An alternative to this test is using RSSI information of beacon signal to find out whether the node is inside the triangular area [35].
- Both the PIT or APIT tests are conducted repeatedly until all combinations of detectable anchor are covered.
- Then to reduce the possible area where target node is present, a central server is used to processed the information.

10. Comparison

Comparison Table For Protocols Based On Computational Design: Centralized and Distributed Approach.[36]

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

Comparison Table Based On Node Mobility: Stationary, Mobile or Hybrid Nodes.[37]

Algorithms	Anchor type	Ranging method	Message communication	Time synchronization	Localization coverage	Localization time	Localization accuracy	Computational complexity	Energy consumption
ALS [12]	Stationary	Range-free	Active	No	Limited	Average	Low	Low	High
HLS [14]	Stationary	TDoA	Active	Yes	Medium	Average	High	Low	High
MLSL [15]	Sensor array	Range-free	Active	No	Large	Average	High	Low	High
PLM [17]	Stationary	Not specified	Active	Not specified	Medium	Average	High	Low	Low
ARTL [18]	Stationary	round-trip	Active	No	Large	Long	High	Low	High
NDLP [8, 9]	Anchor-free	Not specified	Active	Not specified	Large	Long	Low	High	High
LSHL [21,22]	Surface buoys, underwater anchors	One-way ToA	Active	Yes	Large	Long	Low	High	High
RLA [23]	Surface buoys	Not specified	Active	Not specified	Small	Long	Low	High	High
UPS [25, 26]	Stationary	TDoA	Silent	No	Small	Short	High	Low	Low
USP [29–31]	Stationary	Not specified	Silent	Not specified	Small	Short	Low	Low	High
LSLS [32]	Stationary	TDoA	Active	No	Large	Long	Low	Low	High
RBL [34]	Stationary	Two-way ToA	Active	No	Small	Average	High	Low	Low

11. Conclusion

- In this report, a comprehensive survey of recently proposed localization protocols for UWSNs is given based on different classification criteria. The protocols and algorithms are explained in a detailed manner with their merits and demerits. The survey protocols are classified on the basis of computational design, that is whether the algorithm follows a centralized approach or distributed approach, another classification comparison was performed on the basis of Node mobility that is whether the protocol is designed for stationary nodes, hybrid nodes, or mobile nodes. The last classification was on the basis of the underlying technology that is whether the protocol is range-based or range-free. From the comparison section, we can see that we cannot pinpoint any particular protocol as the best protocol but the selection of the protocol depends on the application we want to use it for. For example, if the network contains nodes that are mobile we might want to select a protocol that belongs to that classification and so on.

12. Future Research

Mobility and Network Partitioning

- The localization protocols should consider the mobility of nodes, mobility causes various problems such as partitioning of network. Partition handling schemes must be integrated with the localization protocols. Many of the protocols which are developed currently does not take this problem into consideration.

Security

- Security schemes are implemented in localization protocols for terrestrial wireless sensor networks but the same cannot be done in the case of UWSN because of limitations imposed by the nature of UWSN such as limited battery life, mobility, propagation delays, etc.

Sound Speed Variation

- The localization protocols must consider variation in the speed of sound, localization protocols generally assume that the speed of sound is always 1500 m/s and it is not the case in a reality where the speed of sound may vary with depth, temperature, and salinity of the water.

Synchronization

- Localization protocols generally assume that the synchronization between the nodes is perfect but in reality, strict synchronization is hard to achieve. The protocols must be able to cope up with this limitation and provide accurate location estimations.

Usage of Optical Waves.

- The optical waves can be used for shorter intra-cluster communication to benefit from the high transmission rates whereas for longer transmissions the same acoustic waves can be used. Using the combination of both optical and acoustic waves improves the functionality by reducing contention and higher data rates.

Cross-layer approach

- Internally at lower layers contentions should be considered, such as the mac layer contention. An increase in the contention may cause an increase in convergence time and thus less accurate location estimation.

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