Abstract
As electromagnetic waves do not propagate well underwater, acoustics plays a key role in underwater communication. Due to significant differences in the characteristics of electromagnetic and acoustic channels, networking protocols for underwater systems differ from those developed for wired and wireless radio networks. In this paper, several fundamental key aspects of underwater acoustic communications are investigated. Different architectures for two dimensional and three dimensional underwater sensor networks are discussed, and the characteristics of the underwater channel are detailed. Underwater sensor network removes large and expensive equipment used in ocean monitoring. In UWSN, localization of sensor node is a major problem. Localization is mostly used for presentation of the collected data, tracking the location of underwater nodes, underwater target’s location detection and a group of node’s motion coordination. Localization generally requires object with known location or distance and angle measurement between these known nodes and the object to the unknown nodes. The position of sensor node is predicted by using the reference of the position of neighbor nodes which are having static or mobile behavior. Accurate prediction of location and the localization technique is appropriate for UWSNs [5].

Keywords: Underwater Sensor Network, Localization of UWSN, Acoustic Communication, Fault Tolerance.

I. INTRODUCTION
Underwater Acoustic Sensor Networks (UWASN) is emerging technology that enables timely and effective exploring and monitoring of world under the surface of the water. It enables a wide range of applications like environmental monitoring, ocean sampling networks, disaster prevention and distributed tactile surveillance. The most important advantage of underwater sensor network is the underwater sensor nodes are small and less expensive which are capable of communicating with one another using acoustic signal. Underwater acoustic communication is a technique of sending and receiving messages below water. There are several ways of employing such communication but the most common by using hydrophones. Underwater communication is difficult due to factors such as multipath propagation, time variations of the channel, small available bandwidth and signal attenuation, over a long ranges. Compared to terrestrial communication, underwater - communication has low data rates because it uses acoustic waves instead of electromagnetic waves. In UWSN, localization of sensor node is a major problem. Localization is mostly used for presentation of the collected data, tracking the location of underwater nodes, underwater target’s location detection and a group of node’s motion coordination. Localization generally requires object with known location or distance and angle measurement between these known nodes and the object to the unknown nodes. Accurate prediction of location and the localization technique is appropriate for UWSN. In an Adaptive localization scheme with minimum communication and GPS support is required [5]. Radio signal cannot propagate in underwater environment and hence use of GPS is not possible. In underwater environment, a sensor node knows location of Anchor nodes. If an anchor node failure occurs, a sensor node predicts its position by learning the mobility behaviour of its neighbors using multiple linear regression (MLR). Therefore the data dissemination process can continue even after an unexpected case of anchor node failure. The design of wireless sensor network depends on the following parameters:

- Environment
- System Constraints of limited energy resources, communication range, bandwidth, processing and storage of each node.
- Cost simulators and models
- Hardware platform
- Application domains

The underwater sensors are equipped Autonomous Underwater Vehicles (AUVs) which are find various applications such as exploring the natural under sea resources and the scientific data is gathered for monitoring.

A. Difference between Terrestrial and Underwater Sensor Networks:
The terrestrial sensor networks are designed to operate on the land. It needs air as communication channel for communication. A typical terrestrial sensor network composed of transmitter and receiver part. It uses electromagnetic radio waves for carrying the information of data and voice. Wireless sensor network uses wide number of sensor nodes and hence uses high amount of energy. Traditional routing protocols of WSN [10] cannot be applied directly to UWSN. The following points indicates the major difference between Traditional WSN and UWSN.

- Deployment: The underwater sensor network is easily expand whereas the terrestrial sensor networks are heavily deployed.
Cost: The cost of underwater sensors is much more due to the complex control center and hardware protection for required underwater environment. So, the cost of the underwater sensors is high compared to terrestrial sensors.

Power: The more power is required due to different physical layer technology, more area and signal processing. So, the power required for underwater communication is more to compare the terrestrial communication.

Memory: The terrestrial sensors have finite storage capacity whereas the underwater route may be intermittent so the underwater sensors are not able to do data reserve.

Spatial Correlation: The reading from the terrestrial sensors are correlated which is not possible in underwater sensors network due to larger distance among sensors.

B. Major challenges in the design of underwater acoustic networks are [3]:

1. Bandwidth is limited.
2. Due to the effect of multipath and fading because of the underwater channel is impaired.
3. The propagation delay is higher magnitude compared to the radio frequency terrestrial channels,
4. Error rates will be high
5. Loss of connectivity.
6. Battery power is limited and also cannot be recharged again.
7. The sensors are flat to failure reason of decay and fouling.

C. Applications of underwater sensor networks [3]:

[1] Ocean Sampling Network: The cooperative and adaptive sampling in 3D coastal network the ocean environment can be performed by the network of sensors and AUVs.

[2] Undersea Exploration: The underwater sensor network can be used to find underwater resources or oilfields, can be used to determine the route for underlying cable and finding for valuable minerals.

[3] Seismic Monitoring: The assessment of field performance from underwater fields, the monitoring of seismic is of great importance. The reservoir management is allowed by the underwater sensor network.

[4] Environment Monitoring: The underwater sensor network can be used for the monitoring of the pollution, wind monitoring, and ocean current, biological monitoring. It can improve the detection of climate change, weather forecasting, the effect of human activities on marine ecosystems can be understood and predicted.

[5] Prevention of disaster: The seismic activity can be measured by the sensors can be provide the warning of tsunami, submarine earthquakes etc.

[6] Navigation: The sensor network can be used locate the dangerous rocks, shoals in shallow water, submerged wrecks, etc.

[7] Surveillance: The sensor network can used to monitor areas for target detection, intrusion detection, surveillance, etc.

In underwater networks, the acoustic communication is the physical layer technology. In conductive salty water, the radio waves propagate at extra-low frequencies of 30 to 300 Hz for long distance, this requires large antennas and high transmission power. The attenuation is less in optical communication. It suffers from scattering. Transmission of optical signal requires narrow laser beams. Therefore underwater wireless medium will be used.

II. UNDERWATER SENSOR[3]

The underwater sensor consists of controller to accommodate with an oceanographic sensor through a sensor bond micro circuitry. The controller is receiving the data from the sensor and then to store in onboard memory. The controller can store it, progress it and then send to network devices. The electronics are frequently mounted on the frame because of PVC housing is protected in it. Bottom-mounted instruments are used to protect all sensors which are designed for azimuth omnidirectional acoustic communication and also to protect the sensors in the areas subjected to fishing activities. The quality of water can be measured by the sensor and study of various characteristics like salinity, temperature, acidity, chemicals, pH, hydrogen, turbidity etc.

C. Applications of underwater sensor networks [3]:

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geometric spreading which is the spreading of the sound energy results of the expansion of wave fronts. Geometric Spreading will increase in propagation distance and also independent of the frequency. The transmission loss depends on medium absorption and it degrades the acoustic intensity caused by multipath propagation, diffraction, refraction and scattering of sound.

- **Noise**: It can be ambient noise. The man-made noise is due to machinery noise, shipping activity. The ambient noise is due to hydrodynamics and biological phenomena.

- **Multipath**: The acoustic signal is reduced due to the multipath propagation and it generates inter symbol interference. The link configuration is responsible for multipath geometry.

- **Doppler Spread**: The performance of digital communication is degraded due to Doppler frequency spread. High rate transmission causes interference at the receiver. Doppler spreading is responsible for two effects: Frequency Translation and Continuous spreading of frequencies.

- **High and Variable Propagation Delay**: The propagation delay is higher in magnitude in underwater sensor network. This large propagation delay and variance reduces the throughput.

### III. UNDERWATER ACOUSTIC SENSOR NETWORKS:

#### COMMUNICATION ARCHITECTURE

The 2D architecture of underwater sensor network is shown in figure-2. At the bottom sensor are connected with each other via multi-hop link and then it can pass information to the underwater sink. Underwater sink can pass to this message to the surface station via vertical link. Underwater gateways are the network devices which is used to charge the data from the ocean bottom network to the surface station.

In 3D underwater sensor network shown in figure-3 the sensor nodes float at different depth for observing the phenomenon. At the ocean bottom, each sensor is anchored and equipped with floating buoy which can be inflated by pump. The sensor is pushed by the buoy towards the ocean surface. The depth of sensor can be regulated by adjusting the length of wire which connects the sensor to the anchor. In this architecture sensor will be connected to each other via acoustic vertical link and not used to underwater sink.

#### A. Autonomous Underwater Vehicles (AUV) [8]

The underwater sensor network finds application in oceanography, environment monitoring and underwater resources finding because of absence tethers, cables and remote controls in AUVs. The AUV submarines to using the multiple sensors can reach to the depth of the ocean. The following coordination algorithms are required by the integration of underwater AUV.

- **Adaptive Sampling**: In this the control strategies includes for placing of the mobile vehicles so that most useful information to obtained. High sampling rate is required for monitoring to the environment because of the number of sensor nodes can be increased.

- **Self-Configuration**: This includes the control procedures, which can be for detecting the holes in the connectivity as the failure of nodes and channel. Also used to add new sensors for the installation, the maintenance of the sensor network.

In general, the control strategies are required for the autonomous coordination, obstacle avoidance, and steering strategies. Solar energy systems allows to increase the lifetime of the AUVs.
B. Performance Parameters

- **Communication Cost**: The parameter is used to measure the energy efficiency of the localization scheme. The communication cost is defined in terms of average number of messages transmitted per node for achieving a single localization estimation.

- **Coverage**: The proportionality of ordinary nodes which can be localized successfully is defined as coverage. This is referred as the quality of new reference nodes in multi-stage schemes.

- **Time**: The time taken to achieve the stated coverage either in seconds is the time.

- **Reliability**: The parameter which defines the localization error which is the Euclidean distance between and ordinary nodes estimated and actual location.

IV. STEPS FOR LOCALIZATION TECHNIQUE

A. Range Measurement

Distance is determined by each ordinary node from each reference node which is in its communication range of ordinary node.

Received Signal Strength Indicator (RSSI): The received signal strength is measured for determining the distance of each ordinary node with the reference node and it is compared signal attenuation model which is dependent on the range. When the multipath and shadow fading effect exists it is very tough to achieve accuracy in ranging. The path loss is time varying in the underwater acoustic channel and energy fading is resulted due to the multipath effects. So the RSSI based method for localization is not a good one.

Time Difference of Arrival (TDOA) [1]: Time difference of two transmission mediums is used in TDOA method for calculating object’s distance which uses the transmission method of radio transmission and acoustic transmission. The transmitter’s distance can be determined using two received signals. This is not suitable for location in underwater as the radio signal is not able to propagate through the water. The localization technique uses the time difference of arrival between beacons and all reference nodes.

Time of Arrival (TOA)[1]: The relationship between various parameters like transmission time, distance, speed are used for ranging in this method. Limitations faced in RSSI and TDOA based approaches, this method is widely used the range-based localization. This method requires the time synchronization among network nodes.

B. Location Estimation[1]

The position is estimated by each ordinary node using the intersection various circles centered at each reference node which have been radius based on the range measurements.

C. Calibration [1]

The estimated location is refined using the measurements obtained at various iteration, error models of measurement, models of mobility, etc.

V. TECHNIQUES OF LOCALIZATION

There have been many proposals to localize UWSNs but some of the methods excel in specific ways. Some of the technique of localization are:


This method includes the use of multi-autonomous underwater vehicles (AUVs). In this approach, the position and time is broadcasted by each AUV which are similar to global satellite navigation satellite. The message is received by the nodes which is in the range of its communication and the range differences are detected between sensor nodes and four AUVs. And after that the position is calculated using trilateration method. Multi-AUV Localization Scheme consists of two phases: There is time synchronization among AUVs and from that AUVs the messages are received. It includes the detection of difference between various arrival time of signal between the nodes and the four AUVs and the difference of ranges are calculated.

**Phase 1**: Using trilateration the nodes calculates their position using the position of AUVs and their range differences. The four AUVs exist, their locations are known. Each AUV consist of the acoustic transmitter which has been a fixed navigation satellite. The message is received by the nodes at time tA, tB, tC, tD. The message received by the target node at t’A, t’B, t’C, t’D and time from A to T is Δ ti = t’i – ti . Where i = {A, B, C, D}.

![Figure4. Deployment of A, B, C and D AUVs](image)

**Phase 2**: Location Calculation

\[
(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2 = s_{AT}^2 \hspace{1cm} (1)
\]

\[
(x_2-x_3)^2 + (y_2-y_3)^2 + (z_2-z_3)^2 = (s_{AT} + a_1)^2 \hspace{1cm} (2)
\]

\[
(x_j-x_1)^2 + (y_j-y_1)^2 + (z_j-z_1)^2 = (s_{AT} + a_2)^2 \hspace{1cm} (3)
\]

\[
(x_j-x_3)^2 + (y_j-y_3)^2 + (z_j-z_3)^2 = (s_{AT} + a_3)^2 \hspace{1cm} (4)
\]
Solving above equation,

\[ x = A_x \text{SAT} + B_x \] ...........................................(5)

\[ y = A_y \text{SAT} + B_y \] ...........................................(6)

\[ z = A_z \text{SAT} + B_z \] ...........................................(7)

where,

\[ a = A_x^2 + A_y^2 + A_z^2 - 1 \] ..............................(8)

\[ b = 2(A_xk_1 + A_yk_2 + A_zk_3) \] ..............................(9)

\[ c = k_1^2k_2^2 + k_3^2 \] ...........................................(10)

\[ k_1 = B_x - x, \ k_2 = B_y - y, \ k_3 = B_z - z \] .....................(11)

\[ A_x = b_1 \alpha_1 + b_2 \alpha_2 + b_3 \alpha_3 \] ..............................(12)

\[ B_x = b_1 \beta_1 + b_2 \beta_2 + b_3 \beta_3 \] ..............................(13)

\[ A_y = b_2 \alpha_1 + b_2 \alpha_2 + b_3 \alpha_3 \] ..............................(14)

\[ B_y = b_2 \beta_1 + b_2 \beta_2 + b_3 \beta_3 \] ..............................(15)

\[ A_z = b_3 \alpha_1 + b_3 \alpha_2 + b_3 \alpha_3 \] ..............................(16)

\[ B_z = b_3 \beta_1 + b_3 \beta_2 + b_3 \beta_3 \] ..............................(17)

\[ \alpha_i = 2a_i, \ \beta_i = 2a_i, \ \alpha_3 = 2a_3 \] ..............................(18)

A message containing location information is broadcasted by the AUV node periodically. When an unusual event is detected by the Target node, it accepts the broadcast message. The format of the broadcast packet is as shown in below figure.

<table>
<thead>
<tr>
<th>Node Id</th>
<th>(Latitude, Longitude)</th>
<th>Time of transmission</th>
</tr>
</thead>
</table>

**Figure 5.** Frame format of Broadcast Packet [5]

For localizing the A-node the data available from the S-node are geographic coordinates, TOA, time of transmission, depth measurements and AOA. When the S-node receives packet, the location computation phase will start. A-node is an important node because the computation of the location is dependent on the successful reception of A-node’s packet. If the packet is not available or is corrupted, the situation is treated as the fault [5]. S-node will initialize the fault tolerant procedure and it will determine the corrupted packet. The location is estimated using Equirectangular Approximation (EA). Compared to other techniques based on cylindrical projection, it is more efficient in terms of computation. The TOA measurements are used for calculating the range between A-node and S-node.

**VI. SIMULATION SETUP**

NS2 is a widely recognized and utilized open-source event-driven simulator for developing simulation models in wired and wireless networks. Aqua-sim is installed on NS2 for providing oceanic environment. In simulation as depicted in Part 1, four Autonomous Underwater vehicles (AUV) with different trajectory and single target node is considered. In Part 2, Single AUV and single target node is considered.

**Part 1- Cases of one target and four AUV**

Case 1: Static AUV and Static Target

Case 2: Static AUV and Dynamic Target

Case 3: Dynamic AUV and Dynamic Target

Case 4: Dynamic AUV and Static Target

**Parameters Assumptions:**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameters</th>
<th>Value/protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of nodes</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Transmission time</td>
<td>10 ms</td>
</tr>
<tr>
<td>3</td>
<td>Protocol</td>
<td>Vector based forward</td>
</tr>
<tr>
<td>4</td>
<td>Queue limit</td>
<td>20 ms</td>
</tr>
<tr>
<td>5</td>
<td>Packet size</td>
<td>1000 bytes</td>
</tr>
<tr>
<td>6</td>
<td>Connection type</td>
<td>Duplex</td>
</tr>
<tr>
<td>7</td>
<td>Window size</td>
<td>8000 bytes</td>
</tr>
</tbody>
</table>

**Performance Analysis:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Scenario</th>
<th>Maximum energy consumption(J)</th>
<th>Delay(ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Static AUV and static target</td>
<td>7.564000</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>Static AUV and dynamic target</td>
<td>7.474960</td>
<td>1.75</td>
</tr>
<tr>
<td>3</td>
<td>Dynamic AUV and dynamic target</td>
<td>9.186095</td>
<td>1.91</td>
</tr>
<tr>
<td>4</td>
<td>Dynamic AUV and static target</td>
<td>9.4722156</td>
<td>1.91</td>
</tr>
</tbody>
</table>

**Various Depths:**

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Original location of target (z coordinate-depth)</th>
<th>Location of target based on simulation (z coordinate-depth)</th>
<th>Energy consumed in packet communication(J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-110</td>
<td>-109.9999</td>
<td>7.267200</td>
</tr>
<tr>
<td>2</td>
<td>-120</td>
<td>-119.9999</td>
<td>7.300240</td>
</tr>
<tr>
<td>3</td>
<td>-130</td>
<td>-129.9999</td>
<td>7.367200</td>
</tr>
<tr>
<td>4</td>
<td>-140</td>
<td>-139.9999</td>
<td>7.723363</td>
</tr>
<tr>
<td>5</td>
<td>-200</td>
<td>-199.9999</td>
<td>8.312500</td>
</tr>
</tbody>
</table>
Part2-Cases of one static target and one dynamic target

Case 1: Static AUV and Static Target
Case 2: Static AUV and Dynamic Target

Parameters Assumptions:

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Parameters</th>
<th>Value/protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of nodes</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Transmission time</td>
<td>10 ms</td>
</tr>
<tr>
<td>3</td>
<td>Protocols</td>
<td>TCP</td>
</tr>
<tr>
<td>4</td>
<td>Queue limit</td>
<td>20 ms</td>
</tr>
<tr>
<td>5</td>
<td>Packet size</td>
<td>50 bytes</td>
</tr>
<tr>
<td>6</td>
<td>Connection type</td>
<td>Duplex</td>
</tr>
<tr>
<td>7</td>
<td>Window size</td>
<td>8000 bytes</td>
</tr>
</tbody>
</table>

Performance Analysis:

<table>
<thead>
<tr>
<th>Case</th>
<th>Original location of target (z coordinates depth)</th>
<th>Max Energy Consumption (J)</th>
<th>Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-250</td>
<td>2.42</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>-390</td>
<td>2.42</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>-150</td>
<td>2.45</td>
<td>0.31</td>
</tr>
<tr>
<td>4</td>
<td>-400</td>
<td>2.57</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Comparison table for Part1 and Part2:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Part1</th>
<th>Part2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy (J)</td>
<td>Delay (ms)</td>
</tr>
<tr>
<td>Static AUV and static</td>
<td>7.56</td>
<td>1.9</td>
</tr>
<tr>
<td>target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static AUV and dynamic</td>
<td>7.47</td>
<td>1.75</td>
</tr>
<tr>
<td>target</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VII. FUTURE SCOPE

One of the most critical issues is localization in the underwater sensor network. The most difficult task to achieve the modeling of mobility and fault tolerance. Using multiple linear regression, the position is predicted by the sensor node as it learns the mobile behavior of the neighbors. So even if the anchor node fails the process of the data dissemination continues. Due to the battery of sensor nodes, UWSN has limited energy and also the acoustic communication channel is used so the protocols are required to be developed which have low power requirement in processing and communication overhead. The reception and packets from the anchor nodes are responsible for the success of the localization [5].

VIII. CONCLUSION

In this proposed method localization of target node is done using multi-AUV and single AUV node. Acoustic signals are used to provide connectivity between nodes. AUV broadcasts its intimation along with time and target node executes trilateration method to compute its location. The same is repeated with single AUV and observed that energy consumption and delay are reduced to greater extent. Failure of AUV can be canceled by neighboring node as depicted in future scope.

REFERENCES