TRILATERATION BASED LOCALIZATION FOR UNDERWATER SENSOR NETWORKS

Thesis

Submitted in partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY

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COMPUTER SCIENCE AND ENGINEERING - INFORMATION SECURITY

by

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DECLARATION

I hereby declare that the thesis of the P.G. Project Work entitled **Trilateration based Localization for Underwater Sensor Networks** which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfillment of the requirements for the award of the Degree of **Master of Technology** in **Computer Science and Engineering - Information Security** is a *bonafide thesis of the work carried out by me.* The material contained in this report has not been submitted to any University or Institution for the award of any degree.

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Place: NITK, Surathkal.
Date: $2^{nd} July, 2021$

CERTIFICATE

This is to *certify* that the P.G. Project Work Thesis entitled **Trilateration based Localization for Underwater Sensor Networks** submitted by **Priyansh Kumar Dubey** (Reg, No. 192539IS022) as the record of the work carried out by him, is *accepted as the P.G. Project Work Thesis submission* in partial fulfillment of the requirements for the award of degree of **Master of Technology** in **Computer Science and Engineering - Information Security** in the Department of Computer Science and Engineering, National Institute of technology Karnataka, Surathkal.

Guide
Dr. B. R. Chandavarkar
(Name and Signature with Date)

Chairman - DPGC
(Signature with Date and Seal)

Acknowledgement

At this moment of successful completion of my project work and submission of thesis, first and foremost, I sincerely express my thankful salutations to the Almighty from the bottom of my heart for blessing me with the knowledge and strength at all times during the course of my research till its completion.

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Priyansh Kumar Dubey

Abstract

In underwater sensor networks (UWSNs),determining the location of every sensor is important and the process of estimating the location of each node in a sensor network is known as localization. While various localization algorithms have been proposed for terrestrial sensor networks, there are relatively few localization schemes for UWSNs. This work proposes a new localization technique for underwater sensor networks. In this technique, whenever a new node is introduced in an UWSNs, it will derive its coordinates by examining the coordinates of three of its nearest neighbors. The simulations are performed on an industry-standard agent based simulator - UnetStack.The detailed procedure, along with the background mathematical model, is discussed in this thesis.

Keywords:Beacon, anchors, localized node, blind node, Localization.

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Chapter 1

Introduction

Recently, there has been increasing interest in underwater wireless sensor networks (UWSNs), a primary source for exploring the ocean environment. The UWSN is being developed by the ad-hoc wireless sensor network (WSN) applications and wireless technologies. With the advances of communication and sensor technology, underwater wireless sensor networks (UWSNs) have become a fast-growing field [Rahman et al., 2018]. They have many exciting applications, such as pollution monitoring, off-shore oil exploration, and oceanography data collection [Shakshuki et al., 2019]. Localization is a prominent issue in underwater wireless sensor networks because only the sensor node location data can be successfully decoded by the end-users [Hightower et al., 2000]. If we compare it with the terrestrial localization issue, underwater localization has some fundamental differences because the radio waves used in GPS don't work in water. The Global Positioning System (GPS) technology is unavailable in the aquatic environment because of radio waves' strong attenuation in water [Zhou et al., 2009]. Thus, the underwater node cannot directly locate itself through the GPS. Second, due to the considerable propagation delay in underwater acoustic channels, the cost of maintaining clock synchronization is high and sunken nodes are usually clocked asynchronously. Third, the submerged sensor node's transmitting energy consumption is several times or even hundreds of times the receiving energy consumption.

For naval[Han et al., 2015] defense purposes, UWSNs can provide an immediate deployment option and enhance coastal area surveillance application coverage. UWSNs can be mounted on the bottom of the ocean with underwater sensor nodes that can detect tsunami formations and earthquakes before entering the residen-

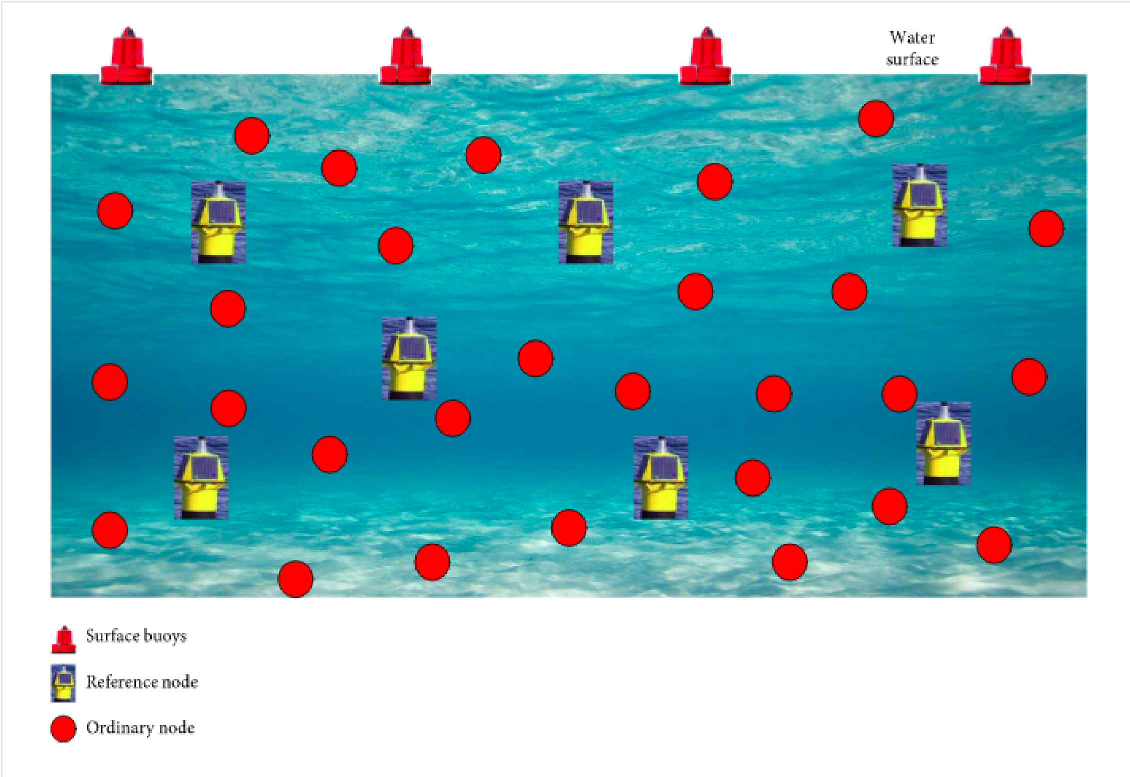

Figure 1.1: Underwater node operation

tial areas.A rough drawing of the underwater node operation is shown in Figure 1. UWSNs can track polluted waters for water pollution detection devices to propagate clean water from their source and warn authorities to take action. UWSNs could be used to monitor coastal creatures and coral reefs, where there is limited data about human activity. Environmental monitoring is also an essential aspect of determining safety and health problems for the environment or human health. Environmental monitoring's primary purpose is sampling soil, water, and atmospheric, but they also need to take the air samples inside buildings to guarantee rules are met. Look for many essential things.

1.1 Underwater sensing applications

Underwater sensor networks are being developed in response to the necessity to feel the underwater world. Fixed or mobile, short or long-lived, best-effort, or life-or-death applications might have a wide range of requirements, which can lead to a variety of designs. Next, define various types of deployments, application classes, and specific examples, both present and hypothetical.

Individual nodes tied to docks, too anchored buoys, or the seafloor are typical examples of static underwater networks (as in the cabled or wireless seafloor sensors in figure 1). Semi-mobile underwater networks can also be suspended from ship-deployed buoys and operated for a short time before being left in place for hours or days. These networks' topologies remain steady for lengthy periods of time, allowing the network topology engineering to promote connectivity. However, network connectivity still may change due to the small-scale movement (as a buoy precesses on its anchor) or water dynamics (as currents, surface waves, or other effects change). When battery-powered, static deployments may be energy-constrained.

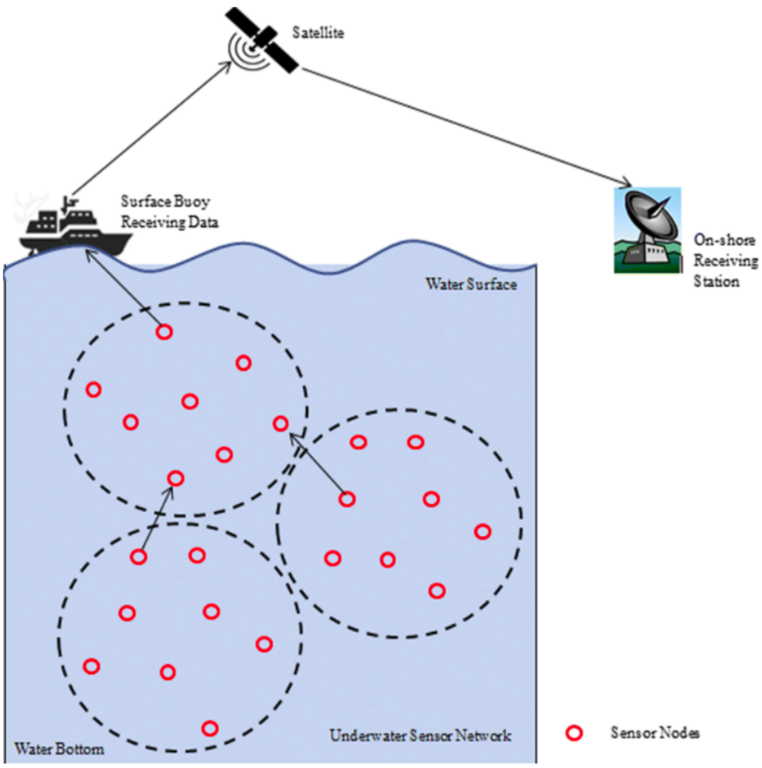

Figure 1.2: Communication through UWSNs

The communication in UWSNs is assisted with one or more surface buoys. A surface buoy is a node that is placed partially above the water level and somewhat below the water level. The purpose of this surface buoy is that it sends the data to the satellite, which further forwards the data to the receiving station situated on the land. So the communication system is not entirely underwater; some part of it is completed above the water level.

In underwater sensor networks, determining every node's location is essential to judge the faults or danger present in the network, and the process is known as localization. As GPS does not work in underwater sensor networks, we need to find some method that can leverage the fact that acoustic modems work well in water compared to RF signals of GPS. In simple terms, localization refers to the process of determining the coordinates of a new node that is introduced in the network by taking the reference of the nodes that are already present in the network.

The node placed inside the water needs to know its location because while collecting important data about its surroundings, the receiver must know where that particular data belongs. The process of estimating the coordinates of a node in the network is known as localization.

This work is focused on implementing a localization algorithm that is quite popular in wireless sensor networks but not used in underwater sensor networks. In the upcoming section, I will discuss different methods of localization that are currently available in UWSNs. Next, I will discuss the mathematical model of the localization algorithm that I am intended to implement. Following this, I will present the step-by-step algorithm for the localization of a blind node introduced in the network and conclude the report and discuss future work. In underwater sensor networks, determining every node's location is essential to judge the faults or danger present in the network, and the process is known as localization. As GPS does not work in underwater sensor networks, we need to find some method that can leverage the fact that acoustic modems work well in water compared to RF signals of GPS. In simple terms, localization refers to the process of determining the coordinates of a new node that is introduced in the network by taking the reference of the nodes that are already present in the network.

Chapter 2

Related work

This is the first stage where I have studied the literature about localization and underwater networks. The study also includes understanding the problems in present methodologies. After this stage, I was able to decide what can be the problem statement of my project.

In this section, a brief description of underwater acoustic communication will be discussed. After that, I will review some of the prominently known schemes typically used in underwater localization. Today, the underwater communication system utilizes EM, optics, and acoustic data transmission schemes to transfer data among the nodes' various locations. The conducting nature of the aquatic environment influences EM communication. Simultaneously, optic waves can only move on very short distances because optic waves are more comfortable in absorbing underwater environments. Therefore, an acoustic communication scheme is only one scheme with better performance compared to EM and optical because of less attenuation in the aquatic environment. Acoustic signals also have less attenuation in the deep and thermally stable underwater field. Acoustic signals attenuate more in shallow than deep water because of the temperature, noise, and multipath reflection and refraction. In the aquatic area, the sound speed is not constant; instead, it varies almost at every point. Near to the water surface, the proper pace is nearly 1500, four times higher than the sound rate in air and slower than the EM and optic speed in air.

2.1 Overview of Localization Approaches

The localization approaches can be divided into two broad categories;range-free and range-based [Isik and Akan, 2009]. Range-free methods usually employ the local topology connectivity to estimate the sensor node's location and obtain a coarser site. In contrast, range-based approaches determine sensor nodes' locations using various ranging methods and provide an accurate location. Ranging techniques can be classified into four categories [Vio et al., 2017]: Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength Indicator (RSSI). The distance information obtained by the TOA method is usually used, such as a vast coverage positioning system (WPS), GPS-less localization protocol (GPS-less), motion-aware sensor localization (MASL), sparse underwater positioning (USP), and 3D underwater localization (3DUL). TOA and TDOA methods require highly precise time synchronization of sensor nodes, which is hard to achieve due to acoustic signal characteristics when traveling in water. In the AOA method, special devices for directional transmission and reception are needed, which increase the cost of localization. The RSSI manner is cost-efficient and convenient because it does not require time synchronization and special devices. Since the RSSI value is vulnerable to environmental disturbances, it isn't easy to get accurate, ranging by directly mapping the absolute RSSI value to the physical distance.

2.2 Range-Based Algorithm

In the range-based algorithm, accurate estimation of distance or angle measurement is made, and TDoA, ToA, and AoA algorithms are generally used for this purpose. Because of constraints like the time-varying characteristics, which are negligible in UASNs, RSSI is not beneficial. On the other hand, the time difference between distinct transmission mediums from specific reference nodes used to assess the distance between two objects is employed in TDoA. ToA, on the other hand, operates the time of arrival using for distance estimation. In the suggested range-based algorithms , the most frequently employed technique for UASNs is the ToA algorithm, and it is favored in UASNs compared to terrestrial. It is smaller than the radio signal in the atmosphere due to the sound velocity in water. ToA is mostly implemented to UASNs, although ToA needed synchronization among nodes. A hybrid bearing and range-based UWSN has been studied in .In, a hybrid bearing and range-based UWSN was investigated. The authors provide a Circle-Based Range-Free Localization Algorithm in the second algorithm (CRFLA) [Tay et al., 2006] to find the unlocated nodes that were unable to obtain position data during the first phase. Finding the location is the conduct of those sensor nodes that were present in the previous phase, such as assisting the new anchor nodes, in the second phase. TDoA, ToA, AoA, and RSSI are all described in detail below.

2.2.1 Time Difference of Arrival (TDoA)

The TDoA is a typical approach for locating underwater; because GPS signals are highly attenuated underwater, a precise range-based algorithm for locating the nodes underwater is required. In the acoustic channel, the authors offer a sequential technique for temporal synchronization and localization[Alcocer et al., 2006]. The transmission source time is unknown, and ToA measurements have a favorable prejudice due to the synchronization mistake, leading to a big localization mistake. One method uses TDoA-based measures to fix this issue, which does not rely on a transmitter source's transmission time. They also use the technique of SDP to turn the nonconvex MLE issue into a convex point. The authors consider it a realistic situation in which nodes are not time-synchronized. Underwater sound speed is also unknown, validating localization as a series of two linear estimation issues—the propagation velocity changes with depth, temperature, salinity, etc. The nodes of the water current are continually moving or their self-motion. The authors define a new associated method based on the directional navigation algorithm used in nodes to achieve precise short-term estimates of movement and using continuous nodes sequential algorithm in an underwater setting for joint time synchronization and location. This method achieves a particular localization environment is utilizing only two anchor sensor nodes and exceeds the benchmark systems when node synchronization and propagation speed data are unknown.

2.2.2 Angle of Arrival (AOA)

The AoA algorithm assumes that all unknown sensor nodes can detect incident signal angles from neighbouring sensor nodes[Amar et al., 2015]. As an antenna, a small array is used, and the phase derivative along the the axis of the array is used as a measure of the apparent sinus of AoA. Perhaps the pronounced DoA lies outside the precise range of arrivals. This is best illustrated by a situation involving two array components with null attenuation. For each node bearing, the AoA capability provides adjacent nodes around the node's axis. Radial is an angle from which an object can be observed from another point or a reversal bearing shortly. AoA-based systems are responsible in circumstances where nodes send their bearings to beacon nodes. In , A scheme used to collect coincident time and AoA information at some GHz is defined. The data processing algorithm is also given, and the results are assessed using data from two different architectures. The measurement consequence employed by Saleh and Valenzuela (1987) in the clustered double Poisson ToA model is used to suggest a model. A correct clustering shape was identified in the time-angle indoor multipath data.

2.3 Range-Free Algorithm

The range-free localization algorithms do not need to use the various bearing information. It only gives a coarse estimation of the sensor position node that is distinct from the range-based algorithm. The author suggested a hybrid localization algorithm with multi-hop, mobile underwater acoustic networks to enhance the localization scheme's effectiveness in a mobile aquatic medium. For this approach, the network's sensor nodes are divided into multistage nodes, each with its own localization operation. To improve localization precision and lower transmission costs, both range-based and range-free techniques are applied. This approach requires no prior knowledge of the velocity of motion, which is commonly utilized in an underwater medium. The range-free algorithm is also divided into three categories: hop count-based, area-based, and centroid methods.

2.3.1 Hop Count-Based Algorithms

In this method, a square grid is taken, and anchor nodes are placed along with the grid's boundaries. Three algorithms are DV-Hope, stable positioning algorithm, and DHL. The DV-Hop utilizes an average estimation of hops' spectrum and the counted number of hops to estimate the anchor node's distance. Robust positioning algorithm is used to raise DV-Hop by inserting an extra refinement step, while DHL may use density consciousness rather than statically estimate distance dynamically. This method is ideal for real-life deployments, where sensor node distribution is more likely to be nonuniform and concentrated in some areas where it is uneven and sparse. DHL has been recommended to improve position estimation accuracy when the network distribution is not uniform [Yang et al., 2007]. This program needs to consider the density of the node's neighborhood calculates the average hop distance, and the wrong facts distance estimates tend to accumulate with increasing path length.

2.3.2 Area-Based Algorithm

Area-Based Localization Scheme (ALS)[Lasla et al., 2014] and approximate point in a triangle (APIT) are the two area-based algorithms. ALS is a centralized range-free system whose primary benefits are the resistance and simplicity underwater to the variable sound speed. They may determine the location of a sensor node inside a functional region, and the sensor node clock must be time-synchronized. It shows the latest recent ALS-based algorithm. The 3D multipower area localization approach, for example, extends 2D-ALS to 3D, whereas APIT necessitates the use of a heterogeneous network. Anchors are equipped with high-power transmitters that allow them to obtain precise location data using GPS coordinates. The underwater acoustic method is generally nonlinear and hard to evaluate, so a correct nonlinear algorithm is required.

2.4 Prediction-Based Localizations

This type of localization algorithms[Song et al., 2011] is used to predict an estimated location of the required node. The exact location of the node is not available through these methods. These localization algorithms use information from more than one node to accurately estimate the location.

2.4.1 Collaborative Localization (CL)

A Collaborative Localization (CL) scheme considering portable UASN applications is where underwater sensor nodes are accountable for gathering ocean depth information and transferring it to the water surface. Two types of underwater sensor nodes are used in this architecture: profilers and supporters. These two types of sensor nodes descend underwater; however, profilers are more resonant than other nodes and come down ahead of them. The distance between profilers and followers is measured on a regular basis using the ToA to determine where the profilers should be placed in relation to the followers. For UASN, the CL algorithm weighed a multipath acoustic propagation channel and a time synchronization technique with increased transmitting delay. Because the statistical model between the real and measuring locations is based on the distance of arrival (DoA), the target position is evaluated using maximum likelihood (MLL) techniques based on the marine channel signal envelope. The suggested algorithm also follows the distributed-centralized computing operation that minimizes the energy transmitting node in USNs.

2.4.2 Distributed Localization

The distribution localization approach allows each sensor node to locate independently, or nodes are free to identify information such as neighborhood distance, anchor location, and connection data, and then communicate it to the reference or supernode individually. The function of position discovery, on the other hand, is dispersed to the sensors themselves in the distributed localization method rather than being placed in a single central unit. Sensor nodes in a dispersed network communicate with one another via peer-to-peer networks (P2P).

In this project, I am assuming that to determine a sensor node, it needs to be in the range of some other nodes whose location in terms of coordinates is known to us. This concept is further explained below.

Case 1: When the node is in the range of at least three other nodes known to us. Using the location of these three nodes, the location of the unknown node is derived.

Case 2: When the node is not in direct range of at least three nodes but has one node in its neighborhood. This neighbor node is, in turn, in the field of two nodes, and by using the location of the three nodes, the location of the unknown node is derived.

Chapter 3

Problem Description

The current techniques[Afzal, 2012] to estimate the coordinates of a blind node in UWSNs have the following problems associated with them:

- Depends upon the hardware for the measurement of the parameters like distance and bearing measures in range based methods.
- Dependency on the strength of the signal to measure the distance.
- While in Range free method the location estimation is not accurate as it only provides the probable location of the blind node.
- The aquatic medium the radio waves cannot be used as he undergo high attenuation[Yoshida et al., 2011].
- Acoustic signals that are used in underwater environment have weak signals and they cannot be used for distance esimation by merely their RSSI(received signal strength indicator) value.

3.1 Problem Statement

One or more new node are introduced in the network. The aim is to find the coordinates of the blind node with the help of the information collected from the neighbouring anchor nodes.

Blind nodes : Node whose coordinates needs to be estimated.

Anchor nodes : The node whose coordinates are already known.

3.2 Prerequisite

The only prerequisite for the proposed solution is that the blind node needs to be placed at a location where it has atleast three anchor nodes in its reachable neighbourhood.

The expected solution should satisfy the following conditions.

- The estimation of distance between two nodes need to be hardware independent.
- The estimation of distance between two nodes need to be independent from the strengh of the signal.
- The solution should work in the medium with high attenuation.
- The location should be given by estimating the exact coordinates of the blind node and not by the probable location.

Chapter 4

Mathematical Modelling

The concept[Schaeffer, 1992] is based on the principle of intersection of three circles which says that three circles will have only one unique point of intersection; there is no way that a combination of three circles will have more than one point of intersection.

The idea here is that if we can get the coordinates of the neighboring three nodes and their distance from the blind node, then we can assume that three circles are drawn with the adjacent nodes as a center, and the blind node must lie on the three circles. Hence it must satisfy the equation of all three circles.

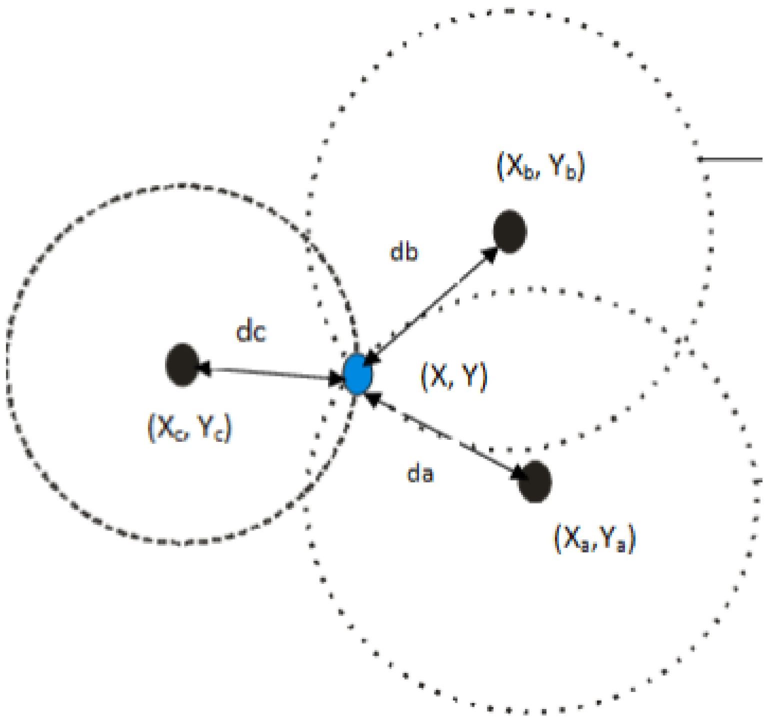

Figure 4.1: Intersection of 3 circles at a unique point

4.1 Expansion and simplification of equations

Following are the equations of the three circles.

$$(X - X_a)^2 + (Y - Y_a)^2 = d_a^2 ....(1)$$

$$(X - X_b)^2 + (Y - Y_b)^2 = d_b^2 ....(2)$$

$$(X - X_c)^2 + (Y - Y_c)^2 = d_c^2 ....(3)$$

These equations can be furthur eXpanded to:

$$d_a^2 = X^2 - 2X.X_a + X_a^2 + Y^2 - 2Y.Y_a + Y_a^2 ....(4)$$

$$d_b^2 = X^2 - 2X.X_b + X_b^2 + Y^2 - 2Y.Y_b + Y_b^2 ....(5)$$

$$d_c^2 = X^2 - 2X.X_c + X_c^2 + Y^2 - 2Y.Y_c + Y_c^2 ....(6)$$

The three equations (4),(5), and (6) are independent non-linear simultaneous equations equation (6) was subtracted from equation (5) and equation (4) was subtracted from equation (5) to get the following linear equations:

$$d_b^2 - d_c^2 = 2X(X_c - X_b) + X_b^2 - X_c^2 + 2Y(Y_c - Y_b) + Y_b^2 - Y_c^2 ....(7)$$

$$d_b^2 - d_a^2 = 2X(X_a - X_b) + X_b^2 - X_a^2 + 2Y(Y_a - Y_b) + Y_b^2 - Y_a^2 ....(8)$$

Rearranging and resolving the above equation, we get the intersection point 'X' and 'Y.'

$$Y = \frac{v_b(X_c - X_b) - v_a(X_a - X_b)}{(Y_a - Y_b)(X_c - X_b) - (Y_c - Y_b)(X_a - X_b)}$$

$$X = \frac{v_a - Y(Y_c - Y_b)}{(X_c - X_b)}$$

where

$$v_a = X(X_c - X_b) + Y(Y_c - Y_b)$$

$$v_b = X(X_a - X_b) + Y(Y_a - Y_b)$$

The values for X and Y gives us an accurate position in two-dimension (2D) for the blind node.

Chapter 5

Proposed Methodology

The mathematical model discussed in the previous chapter is the basis for the project. While in terrestrial networks, the distance between the blind node and the anchor node is calculated by judging the RSSI(received signal strength indicator) value[Benkic et al., 2008] of the signal that means that the signal's strength when received. While implementing the same aquatic medium model, the problem is that in underwater sensor networks, the radio waves cannot be employed as they undergo heavy attenuation in water. In the place of radio waves, acoustic signals are used. The acoustic signal is low strength signals whose strength cannot be measured as precisely as the radio waves, So we need some alternative method to calculate the distance. In this project, I use the round trip time to estimate the distance from the blind node to the anchor node. The methodology will be that as soon as the blind node receives information about three neighboring anchor node's coordinates, it will run an agent at a specific interval to judge the round trip time and thereby the distance value.

5.1 Proposed Scheme

The scheme proposed here is already popular [Xu et al., 2010]in the terrestrial wireless sensor networks, but it is not still employed in the underwater sensor networks. This algorithm aims to determine a specific blind node's location within the distributed nodes along the testbed area. If the blind nodes' positions are not known in a network, these monitors and reports can not be located if need be. The primary obstacles to localization in wireless sensor networks are the sparse anchor node problem; hence, this algorithm is structured to solve it. The proposed algorithm is made up of two phases: the initialization phase and the final phase.

5.1.1 Initialization Phase

Only the anchors will have position data before implementing the positioning algorithm, but all the nodes have identification numbers (IDs). The network is considered for this algorithm will be scalable to a considerable number of nodes, which will be spread over the testbed area. The percentage of anchor nodes will be small. This leads to a situation in which only a tiny percentage of nodes in the network can establish direct contact with any of the anchor nodes. In other to overcome this initial information deficiency, this initialization phase is usually initiated at all anchor nodes by making them broadcast their data, which includes their location position and other parameters sensed. The blind node that is in direct range of the broadcast will store the anchor locations once for a particular node and estimate the range to anchors based on the estimation of round trip time, after which these also broadcast the anchor locations to other blind nodes. Through this process, all blind nodes will know the location of the anchors and their distance.

5.1.2 Final Phase

If a blind node can estimate its distance to at least three anchor nodes; then the blind node can perform trilateration to get its accurate location in 2D; this blind node becomes a "converted" anchor node, its positioning will now be sent to the sink. This process (initialization and final phases) will continue until all blind nodes become converted.

The following pseudocode explains the procedure in a proper algorithmic manner.

Procedure:

1. A broadcast request is made by blind node.

2. **If** anchor node is in the range of blind node

then: respond with its address

endIf

3. **If** blind node gets packets from three different anchors

   then:

   for each address **do:**

   request coordinates information

   calculate the distance using round trip time

   endfor

   endIf

4. **else** repeat 1

5. **If** at least three different anchors identified

   then: Perform trilateration

   endIf

6. **else** repeat 3

7. **If** the trilateration is successful **then:**

   blind node becomes a converted anchor node

   endIf

8. **else** repeat 5

End Procedure

5.2 Evaluation of round trip time

One of the significant steps in the algorithm mentioned above is estimating the distance between the anchor node and the blind node by estimating the round trip time. As compared to the symmetric round trip-based algorithm, this procedure consumes less energy because for the localization of k unknown, let say there are four reference nodes in the neighbourhood of the ordinary node , they are A,B,C and D anchor nodes. To estimate the distance[Karn and Partridge, 1987] between them the ordinary node will send a request and note the time stamp. When it receives the response it will again note the timestamp and from both the timestamp it will estimate the total time taken by the signal in one round trip. As the speed of the signal is known and along with the time ; the distance between the nodes can be calculated.

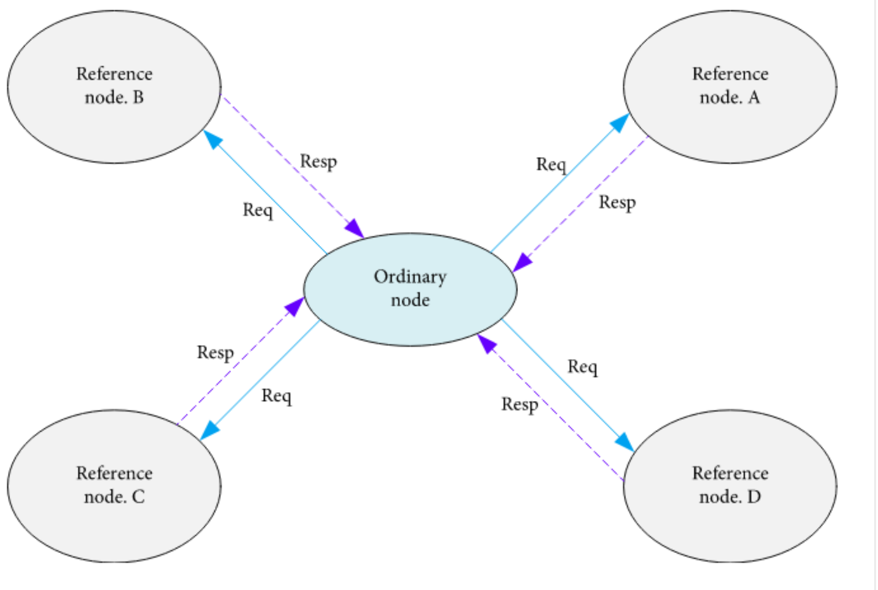

Figure 5.1: Representation of estimation of distance using round trip time.

5.3 Algorithm Implementation

To study the robustness of the proposed localization algorithm, a MATLAB program needs to be developed; this program implemented the algorithm using the input statement and other MATLAB statements, which is more interactive and better for analysis. This is usually called structured programming. The proposed algorithm was developed with MATLAB using structured programming, which involves more of the input statement. For the algorithm to compute the location of the blind node, it needs some input parameters.

I can implement the mathematical model in MATLAB. I have tested the code with some reference points as inputs. The overall Localization error that is present is of the factor of 0.0000006.

5.3.1 MATLAB Implementation

Below is the source code along with the snapshot of the working of the MATLAB code.

```
clear
format long
earthRadiusInMeters = 6371000;
% Coordinates of  A:
LatA = 48.8674546593467;
LonA = 2.355035664087364;

% Coordinates of  B:
LatB = 48.86649526947721;
LonB = 2.355244287413478;

% Coordinates of  C:
LatC = 48.8670763004335;
LonC = 2.356347186129253;

% Theoretical coordinates of the Blind Node
LatD_th = 48.86691223210363;
LonD_th = 2.355337952126204;

% Distances measured Blind node to anchor nodes [km]
DistA = 64.2402 / 1000;
DistB = 46.8676 / 1000;
DistC = 76.0414 / 1000;

[LatD, LonD] = intersectCircles(LatA, LonA, DistA, LatB, LonB, DistB, La

[LatD_th, LonD_th]
[LatD, LonD]


function [lat, lon] = intersectCircles( LatA, LonA, DistA, LatB, LonB, I

% intersectCircles: returns the coordinates of a point over the distance
% Provide the coordinates [decimal degrees] of the reference
% points,and distances [km] to reference points.

% Example:
% long format
% [lat, lon] = intersectCircles (37.418436, −121.963477,
0.265710701754, 37.417243, −121.961889, 0.234592423446, 37.418692, −121
% lat = 37.419102373825389
% lon = −1.219605792083924e + 02

% assuming elevation = 0
earthR = 6371;

% Convert geodetic Lat/Long to ECEF xyz
```

```
%   1. Convert Lat/Long to radians
%   2. Convert Lat/Long(radians) to ECEF

xA = earthR *(cos(deg2rad(LatA)) * cos(deg2rad(LonA)));
yA = earthR *(cos(deg2rad(LatA)) * sin(deg2rad(LonA)));
zA = earthR *(sin(deg2rad(LatA)));
xB = earthR *(cos(deg2rad(LatB)) * cos(deg2rad(LonB)));
yB = earthR *(cos(deg2rad(LatB)) * sin(deg2rad(LonB)));
zB = earthR *(sin(deg2rad(LatB)));
xC = earthR *(cos(deg2rad(LatC)) * cos(deg2rad(LonC)));
yC = earthR *(cos(deg2rad(LatC)) * sin(deg2rad(LonC)));
zC = earthR *(sin(deg2rad(LatC)));
P1 = [xA; yA; zA];
P2 = [xB; yB; zB];
P3 = [xC; yC; zC];

%% Transformation
% transform to get circle 1 at origin
% transform to get circle 2 on x axis

ex = (P2 - P1) / (norm(P2 - P1));
i  = dot(ex, (P3 - P1));
ey = (P3 - P1 - i*ex) / (norm(P3 - P1 - i*ex));
ez = cross(ex, ey);
d  = norm(P2 - P1);
j  = dot(ey, (P3 - P1));
%% Estimation
x = ((DistA^2) - (DistB^2) + (d^2))/(2*d);
y = (((DistA^2) - (DistC^2) + (i^2) + (j^2))/(2*j)) - ((i/j)*x);
% only one case shown here
z = sqrt((DistA^2) - (x^2) - (y^2));

triPt = P1 + x*ex + y*ey + z*ez;
%% Conversion finale
% convert back to lat/long to degrees
lat = rad2deg(asin(triPt(3) / earthR));
lon = rad2deg(atan2(triPt(2),triPt(1)));
end
```

5.4 UnetStack Implementation

This section presents the implementation of the proposed mathematical model in one of the industry-standard agent based underwater network simulator UnetStack3 [Chitre et al., 2014].

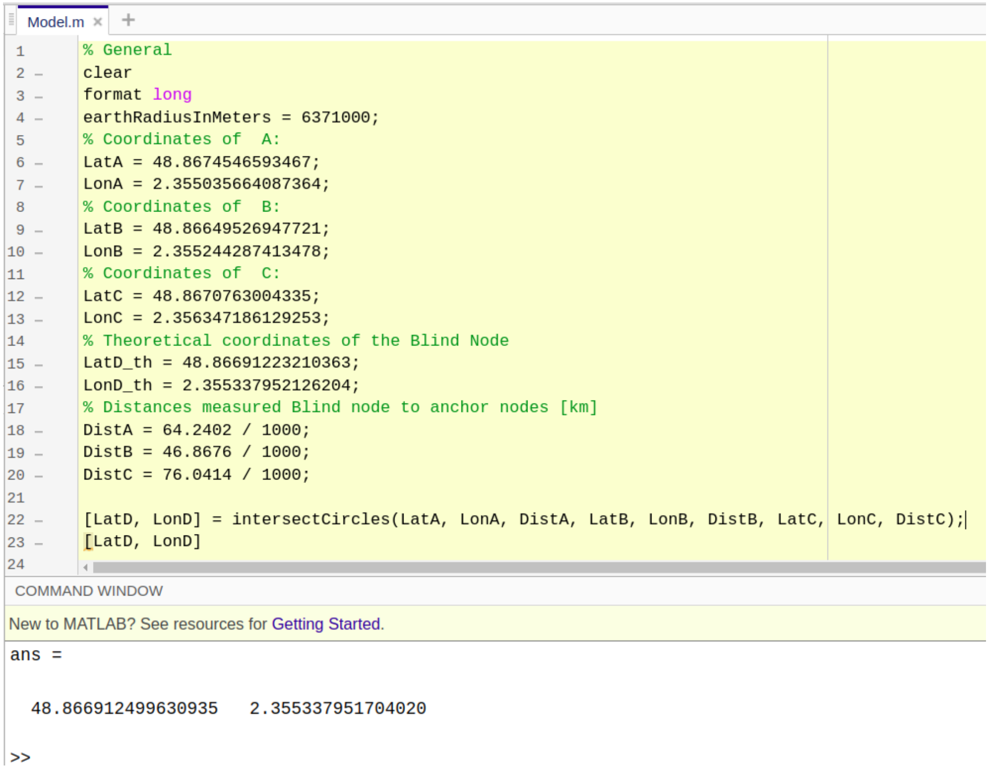

Figure 5.2: Snapshot of the MATLAB code for mathematical model.

5.4.1 Overview of UnetStack

UnetStack is an agent-based software stack and simulator used for UWSNs. There are many AUVs deployed with different sensors. These AUVs need to communicate with each other. UnetStack is one such software stack that makes this possible. UnetStack also has a simulator wherein these scenarios can be created and tested before deploying actual nodes in the ocean. UnetStack has different components such as,

- Unet framework: Which provides the core services, messages, Unet API, and Unet Agents for developers to use. These Unet Agents are built upon fjåge agents. These agents are typically written in groovy or java.
- Unet basic stack: The basic stack includes a collection of different essential agents that are needed by almost all the Unets.
- Unet premium stack: These include a collection of unet agents used for providing higher performance and functionality. They have many similar agents

compared to the basic ones, but they use optimizations to increase the performance and improve bandwidth efficiency.

- Unet simulator: This is the essential tool in UnetStack. It simulates Unets with many nodes. The simulation can be in real-time or discrete based upon the need of a developer.

- Unet IDE: Unet IDE is provided with UnetStack3 soft- ware bundle. It is helpful for developers to develop, simulate, and test Unet agents and protocols. Unet simulator also has a map feature wherein the developer can see the deployed nodes on a map and interact with his nodes during the simulation.

- Unet Audio: This is a new feature in UnetStack. It uses the sound card of a computer to test Unets based on acoustics. It is a great tool to develop networking proto- cols, test them and develop new acoustic communication techniques.

- UnetStack nodes support the mobility of nodes wherein different parameters such as time, duration, speed, and heading can be used to define the motion of nodes.

5.4.2 Localization for static blind node

To localize a node two agents are developed each to be installed on blind node and anchor nodes espectively.

In order to localize a static blind node following algorithm is followed.

- The blind node will first start broadcast request for getting the address of the neighbour nodes.

- As soon as the anchor nodes in the neighbourhood receives the request they reply with a PDU conaining their address.

- At the blind node, the agent will sore the address in a list.

- As soon as the blind nodes receives the addressess from three neighbour nodes, it queries them for getting their ranges.

- In the range response packet itself we can extract the coordinates by using the *getpeerlocation()* function.
- To avoid the collision *Waker behavior* is employed in querying the ranges. It triggers the anchor nodes to respond at different times.

5.4.3 Localization for mobile blind node

The problem with mobile nodes is that by the time the localization is completed the node might move to a new position. So during the estimation if we know the speed with which the node is moving, we can get the distance covered by it in a given time frame. Adding this distance to the estimated coordinates we can get the actual coordinates of the nodes at that time. Fig.5.3 represents the concept.

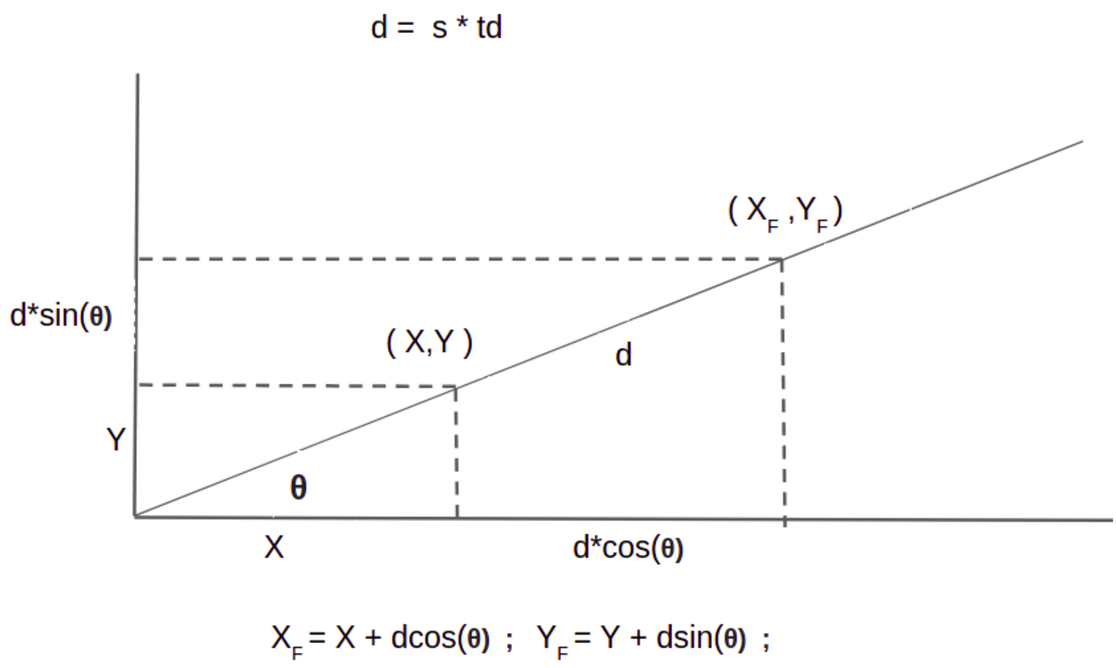

Figure 5.3: Localization for mobile blind node

In order to localize a static blind node following algorithm is followed :

- The blind node will start broadcast request for getting the address of the neighbour nodes.
- The current timestamp is saved in a variable 'start'.

- As soon as the anchor nodes in the neighbourhood receives the request they reply with a PDU conaining their address.
- At the blind node, the agent will sore the address in a list.
- As soon as the blind nodes receives the addressess from three neighbour nodes, it queries them for getting their ranges.
- In the range response packet itself we can extract the coordinates by using the *getpeerlocation()* function.
- To avoid the collision *Waker behavior* is employed in querying the ranges. It triggers the anchor nodes to respond at different times.
- After getting the ranges and coordinates information from the anchor nodes, the coordinates of the blind nodes are estimated.
- The estimated coordinates might be different than the current coordinates because during all this time the blind node has travelled some distance.
- Therefore the estimated coordinates are updated as shown in the Fig.5.3

5.5 Metrics for Evaluating Algorithm

5.5.1 Localization Error

Localization Error is defined as the distance between the estimated and the actual coordinates of the node. It is computed using the equation:

$$Error = \sqrt{(x_e^i - x_a^i)^2 + (y_e^i - y_a^i)^2}$$

where (x_e^i, y_e^i) and (x_a^i, y_a^i) are node i's estimated and actual coordinates.

5.5.2 Total time taken by the algorithm

The algorithm's total time to execute should not be very high, as it will lead to low performance. The ideal situation will be that the algorithm completes its execution and updates the coordinates on the map within a reasonable time.

Chapter 6

Results and Conclusion

6.1 Simulation Setup

- I have simulated a topology of 4 nodes is simulated in an area of 3000m×3000m. The anchor nodes are static.
- For mobile blind node I assume that the speed is 1m/s. The interval of reponse to broadcast request varies from 1s to 4s. I
- The mobile node moves in a straight line triggering the localization algorithm after every 2 minutes.
- For the first 2 minutes the blind node will be stationary. Next for 10 minutes it will move in a straight line and at last it will stop after travelling for 10 minutes and stays there forever.

6.2 Observations

Following observations were made:

- For the stationary blind node the estimations are very accurate resulting an error of 0.00038 m
- For mobile nodes as we increase the speed of the blind node the error increases linearly (Fig.6.1). It happens because of reception of responses from the anchors at different locations.
- For the speed of 1mps It has an error of 10m on average.

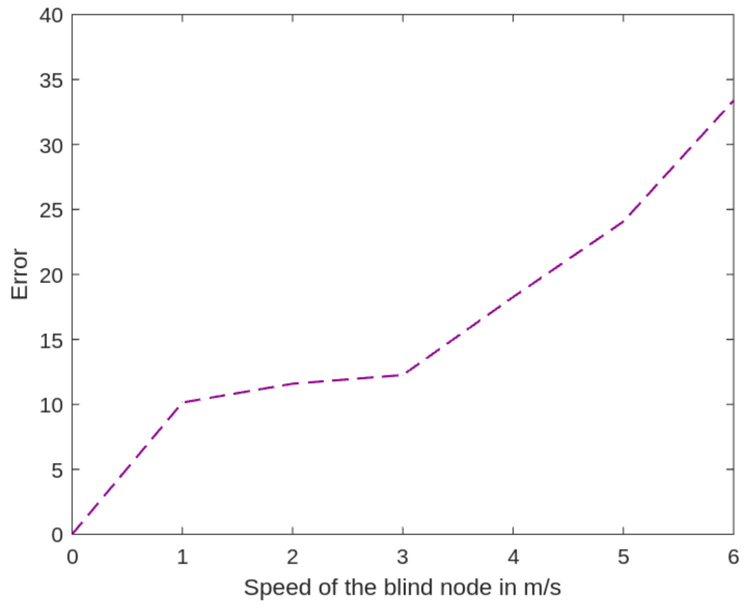

Figure 6.1: Variation of error with speed of blind node

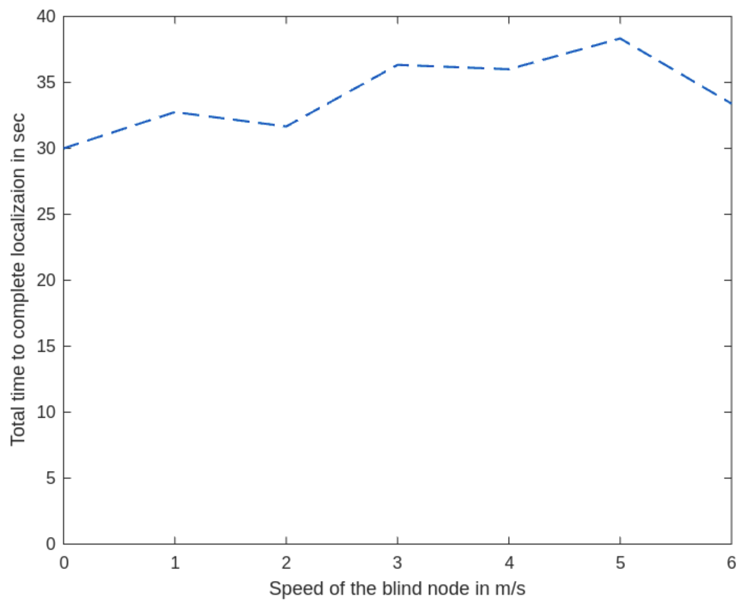

Figure 6.2: Variation of time with speed of blind node

- Fig.6.2 shows that the total time taken for completing the algorithm is between 30s to 40s irrespective of speed of blind node.
- If we try to furthur reduce the time, it may leads to collision as it is a unicast communication.

6.3 Conclusion

Localization is an essential part of any wireless sensor network. In this work I addressed the problem of localization for UWSNs using trilateration method that is quite popular scheme in terrestrial wireless sensor networks. The area of underwater wireless sensor networks differs from the terrestrial network because the acoustic transmission medium poses a different attenuation problem, which is not present in the terrestrial network. This work attempts to deploy one of the popular algorithms of terrestrial networks in underwater sensor networks. The difference made here is that while in terrestrial networks, the algorithm depends upon the value of RSSI to estimate the distance, I am trying to calculate the distance using round trip time. First, I discussed the application of underwater sensing. After that the related work about the present localization techniques is presented. A novel approach based on mathematical model is presented next and based on the mathematical model, I proposed solutions for static and mobile blind nodes. Finally,I analyzed the simulations and presented the results. It is observed that the algorithm gives very accurate results for the case of static blind node.For mobile blind node the error increases propotional to the speed of the node. In future, attempts can be made to make the algorithm more accurate with increasing speed of the blind node.

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