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Localization in Underwater Acoustic Sensor Networks using Trapezoid

B. S. Halakarnimath, A. V. Sutagundar

Abstract*: *Underwater Acoustic Sensor Networks (UASN) has driven a lot of attention from researchers because of advancements in sensor technology and unexplored applications of the ocean. UASNs monitor the targeted area with heterogeneous underwater sensors and relay that information to the onshore sink node in mission-critical applications. It is very much essential to know the source of information whenever some critical events happened in the UASNs. Hence, to learn the source of information, i.e. finding the location of the sensor node is crucial. To address this issue, in this paper, initially geometrical object such as trapezoid is used to form the clusters in the targeted region. After that, the proposed localization algorithm is applied and it works in three phases. (i) In the first phase, the sink node initiates the trapezoid formation process through Trapezoid Formation Agent (TFA) and divides the whole network into trapezoids of different geometrical shapes by traveling across the linear trajectory and also creates a search data structure. (ii) In the second phase, the sink deploys AUV at a certain depth for patrolling along the linear trajectory and broadcasts real-time location contained beacon messages at specified points through that anchor nodes are localized by using RSSI. (iii) Sink node activates Localization Agent (LA) in the third phase to perform the location identification process at the trapezoids by using the trilateration method. This work addresses the inherent localization issue of UASNs algorithms and hence it applies to the applications which consider the localization issue. This proposed scheme is well supported by node agencies and knowledgebase. The proposed scheme is simulated in C and validated by different performance parameters.

Keywords* : *Localization, Node-agency, Trapezoid, UASN.

I. INTRODUCTION

The Underwater Acoustic Sensor Networks (UASNs) consists of several acoustic sensors, surface buoys, AUVs, sink stations, etc. form an ad-hoc wireless network and achieve the desired task in real-time. These UASNs are more useful in applications for an exploration of naturally available

undersea resources and to gather scientific data in critical missions. To make these desired tasks viable, UASNs need to enable underwater communication among submerged devices. The acoustic sensor nodes and AUVs must possess self-adaptive capabilities and send the processed/ monitored data to an onshore sink-station [1].

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* Correspondence Author
Mr. B. S. Halakarnimath*, Research scholar of VTU, ,S. G. Balekundri Institute of Technology, Belagavi, India
Dr. A. V. Sutagundar, Associate Professor, Dept. of ECE,Basaveshwar Engineering College, Bagalkot, India.

The gathered information must include the sensor nodes' location to provide a proper view of the perceived field and hence, localization protocols are important for UASN. It comprises various techniques and mechanisms that allow a sensor node to estimate location based on information collected from the sensor's environment. The localization technique depends on the

deployment techniques, channel constraints, mobility factors, underwater devices, and their related hardware components. The sensors are exposed to failures because of fouling and corrosion.Localization for larger-scale UASNs is challenging because of harsh aqueous environments. In addition to that, the acoustic communication characteristics such as low bandwidth, channel conditions, high error rate become limitations for the localization schemes [2]. The propagation

delays, phase and amplitude fluctuations, multipath interference, motion-induced Doppler shift, etc. are all important factors in location measurement [3]. Some of the localization issues are given as follows. (i)Proper sound speed variation model (ii)Time synchronization for submerged nodes (iii) Node mobility model for various sea environments. (iv)Managing the impacts of Medium Access Control (v)Impact of localization algorithms on location-based clustering and routing protocols. The significant contributions from many researchers [3], [4], [5], [6] related to the localization issue is mainly focused on finding the nodes' location by not considering the underwater environments. Many of these contributions did not consider the computational geometrical fundamental approaches. This triggers us to design and simulate an algorithm based on the computational geometrical techniques by incorporating the dynamic characteristics of the ocean.

Outline of the proposed scheme is as follows (i) In the first phase, the sink node divides the targeted sea surface into slabs and initiates the trapezoid formation process by Trapezoid Formation Agent (TFA). The TFA follows given AUV linear trajectory at the different depth levels of the ocean surface and stores the trapezoidal information and searches data structure on the sink knowledge base (SKB). Node related information is stored at the Node Knowledge Base (NKB). (ii) In the second phase, the sink activates Localization Agent (LA) and installs AUV at a certain fixed depth of the ocean surface. (iii) (iii)The AUV moves along the fixed linear trajectory and broadcasts real-time location beacon messages at specified points on the trajectory. (iv) The Anchor Agent (AA) at anchor node gets these messages and measures RSSI. (v) The anchor node is re-localized itself based on the real-time location of the broadcast point and RSSI. (vi)

In each anchor node's associated trapezoid, the localization agent initiates the location finding process by using the trilateration method. (vii) All the agents update modified information onto the SKB and NKB. Our contributions are as follows (i) Setup of the network architecture (ii) Applying the trapezoidal map to create the various trapezoids of different shapes. (iii) Designing the AUV's trajectory to travel and periodically broadcast real-time location information.

(vi) Designing suitable node agencies for the proposed scheme. (v) Developing the algorithms for trapezoid creation and localization process. (vi)Simulating the proposed localization scheme using C programming language. (vii) Validating the proposed localization scheme with various performance parameters. The organization of this paper is as follows. The literature survey is reviewed in section II. The proposed model is presented in detail in section III. Section IV, presents a simulation model and simulation procedure. The evaluation of the proposed scheme is given in section V. This work is concluded with future directions as presented in section VI.

II RELATED WORK

The wide spectrum of unexplored underwater applications has become the prominent research area of many researchers. The localization issue is addressed by many researchers and developed different algorithms/ methods/techniques. Here some of the key contributions are summarized as follows. In [4], energy measures of acoustic signals are used to estimate the locations of many acoustic sources in terrestrial networks. For single target location estimation, accuracy and its analysis of impacts are done by using Cram´er–Rao Bound (CRB). ML method produces better accurate results and gives the enhanced capability for multiple source localization. This method is scalable for more than one target within a defined sensor field. This work provided significant information about acoustic signals for underwater sensor networks. [7] Estimated the coarse location of a sensor instead of an exact location within a fixed area. A sensor node hears beacon signals from multiple anchor nodes and stores its power levels separately and computes mode or mean of stored power signals of every anchor node. This stored information is forwarded to the sink to find out the area in which it resides. This method is simple, synchronization free and compatible with the varying speed of sound. [8] Presented event-driven recursive distributed localization scheme. This scheme has the advantage of providing good throughput even though beacon nodes are in fewer numbers. The scheme fails to address the mobility issue of uw-sensor nodes.

Localization is not so easy in the underwater environment if reference/anchor nodes are pre-deployed [9] designed for shallow water environments to overcome the errors related to the stability of the Line Of Sight (LOS) link. To classify LOS/NLOS, received signal strength (RSS) is used. To estimate the position angle of arrival (AoA) is used and is independent of the LOS connection. Finite-Difference-Time-Domain (FDTD) a method is used to determine the reflection points for a near line of sight (NLOS) positioning. This scheme needs more anchor nodes which may not be feasible for a larger network. In [10], many sensor nodes are deployed in the underwater environment in various places. Localization is energy efficient because sensor nodes keep moving continuously due to the shipping activities or inherent dynamic nature of the underwater waves hence localization of these sensor nodes' is possible within a shorter duration. This scheme may face the issue of sustainability of a network of sensor nodes that are move out of the operational field of the network. [11] Addressed the uncertainty of the deployed anchor/reference node position. Anchor/reference nodes are exposed to underwater environmental characteristics as a result, mobilization takes place in their position which cannot be neglected to compute the location of un-localized sensor nodes. [12] Proposed a scheme to minimize the localization time by considering the collision tolerant and collision-free packet transmission schemes. In [13], the author proposed a range based distributed method for anchor nodes' localization and range free centralized method for ordinary nodes' localization. The aim was to achieve high localization ratio and simulation results have achieved better results. [2]This hierarchical localization of the approach is divided into anchor node and ordinary node localization by predicting the mobility pattern of previously known location information and predicted mobility the pattern helps to compute sensor node future location. This scheme reduces communication costs, provides high coverage and accuracy.

III. PROPOSED WORK

In this section, we present the network model and novel algorithm for finding the location of sensor nodes using computational geometry. The issues like cluster formation, energy utilization, topology control are inherent and play a crucial role in designing the localization algorithm. The proposed localization scheme is discussed as follows (i) The network architecture is explained in section III-A. (ii) The proposed agencies are presented in section III-B (iii) The computational geometry based trapezoidal map is presented in section III-C. (iv)The AUV's trajectory is designed to travel and periodically broadcast real-time location information is presented in section III-D. (v) The proposed localization scheme is presented in III-E.

A. Network Environment

In three dimensional UASNs, uw-sensors are deployed at different depth levels of the sea to monitor the targeted area. In this work, a three-dimensional underwater acoustic sensor network consists of surface buoys, Autonomous Underwater Vehicles (AUVs), anchor nodes, and ordinary underwater sensor nodes. These nodes operate in two states. (i) Active state: In this state, the node can sense, process, receive and transmit the data. (ii) Semi-active state: In this state, the node can sense the data and receive the signals. It cannot process and transmit the data. The AUVs are submerged at different depth levels in the sea surface and keep traveling on the given trajectories. Anchor nodes are deployed randomly at different levels of the ocean. These anchor nodes are assumed to be stationary and also called as reference nodes.

Underwater sensor nodes randomly and uniformly deployed in the target monitoring area of the ocean. Each uw-node can anchor, communicate and mobile in nature. The network environment is shown in fig. 1. For this underwater sensor network, the energy consumption model is based on sound waves. The AUVs are equipped with more capabilities than the anchor nodes and uw-sensor nodes. The network model has few numbers of AUVs and the number of uw-sensors (equipped with pressure sensors) is freely dropped in the ocean.

AUVs and anchor nodes together form an ad-hoc network on the plane O. When the AUV dives at a certain depth and navigates, it can compute its coordinates by using dead reckoning and compass with a minor error. In this work, AUVs assist nodes' to localize themselves with the help of anchor nodes. Some anchor nodes are also deployed on the plane to act as reference points and to assist localization across the seabed. The target region of sea area O is a planar subdivision of size $O_l \; X \; O_b \; X \; O_d$. The depth of the sea is divided into several vertical levels. On each layer i.e. on horizontal plane initially, AUVs are placed at a fixed depth. AUVs are capable to get their location from GPS directly and can communicate with the anchor/reference nodes covering a larger range. The TFA creates trapezoids on each layer (explained in section III-C).

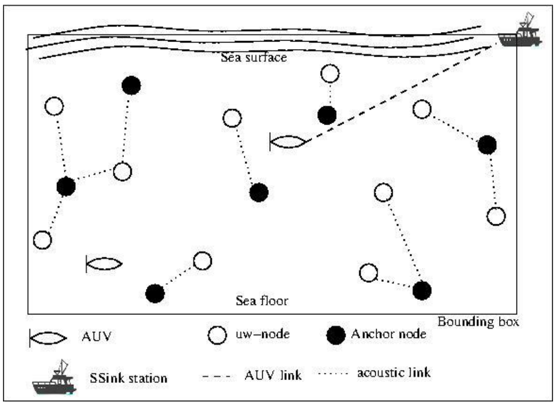

Fig. 1 UASN architecture

It is assumed that the boundary of every trapezoid $T_i \; or \; T_j \; (i,j \; \leq \; n)$ is disjoint without overlaps and gaps i.e. trapezoid region $T_{i,j} \subseteq O$ and $T_i \cap T_j = \emptyset$ where $i,j \; \leq n$. Since AUV can communicate in all directions, locating the nodes is possible if the anchor nodes are present anywhere in the coverage area. The network is deployed with anchor nodes at various depth levels and learns their locations whenever they come under the communication range of AUV by using the RSSI technique. These anchor nodes are assumed to be stationary in nature. Consider a planar graph G(V, E), where anchor nodes are vertices and communication links between these vertices are edges/segments.

B. Proposed Agency

In this section agencies are used at the sink, anchor and underwater sensor node are presented. Each underwater node consists of an agent platform and a proposed Localization model. The underwater node, anchor nodes, and sink node comprise with sink agency, anchor agency, and node agency to perform the assigned task.

1) Node agency

Node agency consists of a static agent NA, mobile agent NMA, and LA for intercommunications of agents as shown in fig. 2.

Node Agent (NA): It is a social, autonomous, and reactive agent. It resides locally at the underwater node level. It uses NKB to store and retrieve the information. This agent interacts with the Localization Agent (LA) to assist in the localization process.

Node Manager Agent: It resides in every underwater sensor node of the network. The responsibilities of NMA at underwater sensor node level are

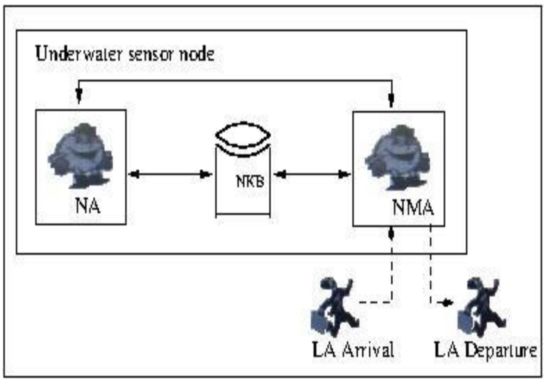

Fig. 2 Node agency

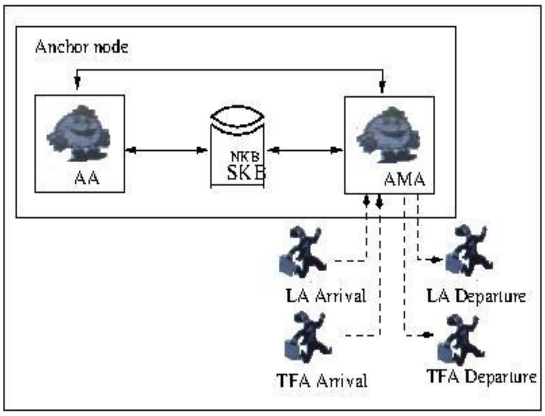

Fig. 3 Anchor agency

(i) Change the node state from the active state into the semi-active state and vice-versa. (ii) Interact with the outside world and synchronize the actions (iii) Involve in the localization process with LA. (iv) Manages the node's battery effectively for longer life. (v) Update the NKB. The LA interacts with NMA for the localization process. The NMA decides about the localization by checking the current status of the node. If the localization is required it assists the LA and updates the same in NKB. It also sends the location and battery information along with LA to the sink node.

2) Anchor Agency

Anchor agency consists of static agent NA, mobile agent NMA, TFA, and LA for intercommunications of agents as shown in fig. 3.

AUV Agent (AA): It is a social, autonomous, and reactive agent. It resides locally at the underwater node level. It uses NKB and SKB to store and retrieve the information. This agent resided at anchor node involves in the trapezoid formation process and the localization process.

Anchor Manager Agent: It resides in every anchor node of the network. It is the same as underwater node NMA and additional responsibilities are (i) Involve in the Trapezoid Formation process with TFA. (iv) Create search data structure D. (iii) Update the modified information onto the NKB and SKB.

3) Sink Agency

Sink agency consists of static agent SA, mobile agent SMA, TFA and LA for intercommunications of agents as shown in fig. 4.

Sink Agent (SA): It is a social, autonomous, intelligent, adaptive, mobile and pro-active agent. It resides locally at the sink node level. It uses SKB to store and retrieve the information. This agent interacts with TFA and LA to assist in the localization and trapezoid formation process.

Localization Agent (LA): It is a social, autonomous, mobile and pro-active agent. It establishes the interaction between NA, SA, TFA, SKB, and NKB. It interacts with TFA to get the information for localization. LA is triggered by the sink node to perform the localization process at each trapezoid and updates the information into a knowledge base.

Trapezoid Formation Agent (TFA): It is a social, autonomous, mobile and pro-active agent. TFA is triggered by the sink node and the key objective is the formation of trapezoids and construction of the search data structure as per the given network. It interacts with LA to assist in the localization process.

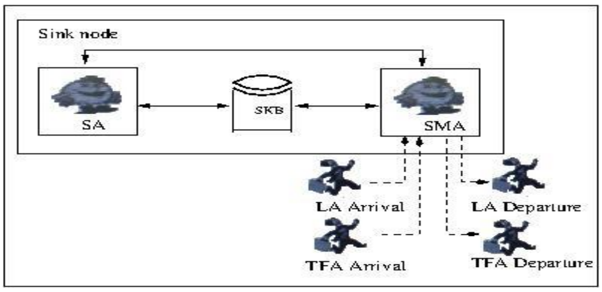

Fig. 4 Sink agency

Sink Manager Agent: It resides at the sink node of the network. The responsibilities of SMA are (i) Interact with the outside world and synchronize the actions. (ii) Activates TFA during pre-localization, LA during the localization and maintains search data structure D. (iii) Involve in the localization process with LA and Trapezoid Formation process with TFA. (iv) Manages underwater sensor nodes' battery effectively for longer life. (v) Update the SKB. (vi) SMA interacts with NMA for the localization process. The SMA decides when to initiate the localization process by checking the current status of the network. The following node knowledge base agencies are used.

Node Knowledge Base (NKB): This is a local knowledge base at each node level. This knowledgebase contains N_{ID}, N_{TID}, N_{ER}, N_{SR}, N_{CR}, $N_{(X;Y;Z)}$, N_C and sensed information. All the agents interact with this knowledge base to access, edit and modify the information.

Sink Knowledge Base (SKB): This is the sink node's knowledge base and shared with TFA and LA during localization time. This knowledgebase contains the information of the uw- node, AUV's trajectory, trapezoid information, etc. The NA, AA, and TFA interact with this knowledge base to access, edit and modify the information.

C. Formation of Clusters/trapezoids

The sink node initiates the cluster formation activity with the help of AUV and Trapezoid Formation Agent (TFA). The linear trajectory at fixed depth levels is followed by the AUV. On the trajectory, the TFA divides the horizontal plane into several vertical slabs and stores vertices' x-coordinate in sorted order on the Sink Knowledge Base (NB). The TFA further divides each slab into trapezoids with the help of anchor/reference nodes. Each region in the vertical slab between 2 consecutive edges is having a unique trapezoid. The sea surface and seafloor area are bounded by some trapezoids within the boundary regions. The edge and vertical lines through the endpoints form geometrical shapes such as triangles, trapezoids, and unbounded trapezoids as shown in fig. 5. To find out the trapezoid of the underwater node a binary search is applied to the stored array of x-coordinates as shown in figure 7[14].

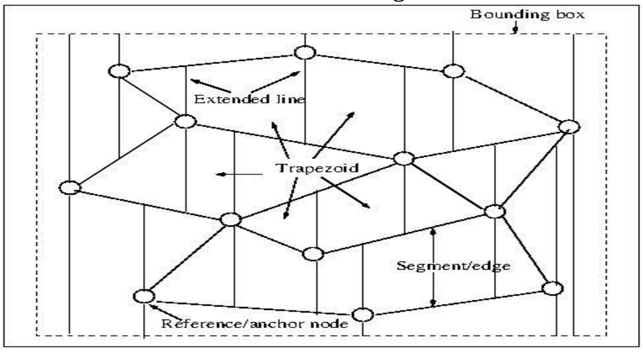

Fig. 5 Trapezoidal map [14]

Now the graph has set of non-crossing line segments, $S=\{s_1, s_2, \ldots, s_n\}$, enclosed in the bounding-box R, and with the property that segment's endpoints are not lying on the common vertical line. If a network has a set of non-crossing edges, edges endpoints are not lying on reference vertical line and bounded by defined boundaries then it becomes easier to construct a trapezoidal map. The TFA constructs the trapezoidal map T(S) for the non-crossing edges of vertices in the plane. Assume that the x-coordinate of any two vertices (reference nodes) are different in the plane. The TFA extends two vertical lines from each reference nodes one towards upward and another one towards downward till they meet another edge or boundary of S as shown in fig. 5 of the trapezoidal map. If any two trapezoids are adjacent, then they share along a vertical edge. A doubly-connected edge is used in the construction of the trapezoidal map.

Search data structure: The TFA also constructs the search data structure D to identify the trapezoid in which underwater nodes are present as shown in fig. 6. Search structure D has the following properties. (i) It is a directed acyclic graph (DAG). (ii) It has a single root, and every trapezoid is represented by leaf in the trapezoidal map S. (iii) Out-degree of inner nodes is 2; x-node and y-node where x-node is marked with the endpoints of any segment in S and y-node are marked with the segments itself. The search data structure and the trapezoidal map are interlinked with each other.

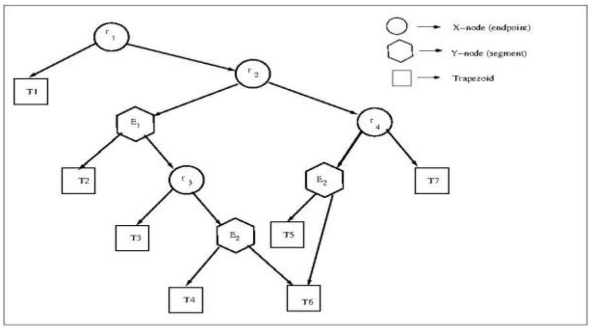

Fig. 6 Search data structure

D. AUV Trajectory

The AUV traverses along the linear trajectory of a length *l* from starting point T_{start} till endpoint T_{end} horizontally at a certain depth with uniform speed. The AUV periodically broadcasts beacon messages in omnidirectional at regular intervals containing real-time location information at a certain transmission power as shown in figure 7.

Localization Agent (LA) which is resided at anchor a node receives these messages and also measures the received signal strength indicator value of each message. The LA calculates measured RSSI value in the network environment as per [15] is expressed in equation (1)

$$R_{SL} = SL + NL - PL(l) \qquad (1)$$

where SL is the source level is expressed in (2), NL is the noise level is expressed in equation (5), PL(l) is the propagation loss for an acoustic signal in the underwater environment is expressed in equation (3)

$$SL = 10log\frac{I_t}{1\mu Pa} \qquad (2)$$

where I_t is the transmitted signal intensity at a distance of 1m is measured in μPa.

The propagation loss is given in equation (3)

$$10\log PL\,(d,f) = k.10\log(d) + d.\ \alpha(f) + A \qquad (3)$$

where k is the geometrical spreading factor of propagation, (f) is the absorption model given in equation (4), and A is transmission anomaly which excludes absorption factors and includes factors such as scattering, diffraction, and refraction.

The spreading factor of **k = 1.5** is considered. Spreading loss is frequency independent and it is either spherical spreading

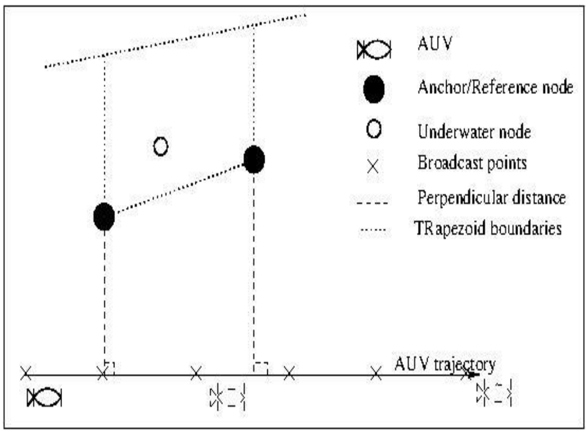

Fig. 7 AUV Trajectory

or cylindrical spreading. Thorp's formula [16] defines α(f), the absorption model for frequencies is given in equation (4)

$$\alpha(f) = \Big(0.11\,\frac{f^2}{f^2+1} + 44\,\frac{f^2}{f^2+4100} + 2.75.10^{-4}f^2 + 0.003.\,10{-}3 \qquad (4)$$

where α is the absorption factor measured in dB/km, and f is the frequency in kHz. The noise in the acoustic underwater-channel comprises thermal noise $N_{tn}(f)$, shipping noise $N_s(f)$, waves noise $N_w(f)$ and turbulence $N_{tu}(f)$ in dB re μPa per Hz[17]. The overall noise level is calculated as given in equation (5)

$$NL(f) = N_{tn}(f) + N_w(f) + N_s(f) + N_{tu}(f) \qquad (5)$$

in Pa/Hz.

Consider any broadcast point location is (x,y,z) on the AUV trajectory and (x_r, y_r, z_r) is any anchor node location on the sea surface. The z is 0 due to linear movement, and the y-coordinate is linearly represented by x because of the AUV trajectory which is a straight line on the sea surface. The LA gets the RSSI value vector of all broadcast points and the X coordinate vector of broadcast points and determines the location of an anchor node by applying the distance formula. Once the anchor nodes are localized, LA moves to each trapezoid and performs the localization for every un-localized node as presented in algorithm 1. The localization algorithm 1 is presented in section III-E.

E. Proposed Localization Scheme

Initially, all the uw-nodes are in a semi-active state i.e. they can sense and receive the signals from anchor/ reference nodes so that the energy consumption of the uw-node is minimized to a greater extent. They are unable to transmit the sensed information until they are localized and made active.

Algorithm 1 Localization of un-localized anchor nodes

function LOCALIZATION(D,T)
while $\{N_{failure} \le (N - \frac{LP}{100} * N)\}$ **do** // LP← lifetime %
  Sink Initiates the localization process by triggering LA.
  $AUV_d = 100$ //Initially AUV depth is set to 100m
  while $\{ AUV_d \le O_d \}$ **do** //Till AUV covers all layers
    Change all the underwater nodes state into semi-active
    while $\{ B_{point} \le T_{end} \}$ **do** //till it reaches end
      AUV broadcasts beacon message b_m at B_{point}
      for {each anchor node $A_i \le AUV_{CR}$} **do**
        LA at anchor node measures signal strength and receives beacon message
        Anchor node re-localize itself.
        Compute energy consumption and update N_{ER}
        trap[] = Get trapezoids associated with A_i
        perform localization within the trapezoid
      end for
    end while
  end while
  Get the numbers of failure nodes
end while
end function

IV. SIMULATION

The performance of the proposed localization scheme is validated by using C simulation.

Initially, the simulation begins with changing all the underwater nodes state into a semi-active state. After that, the simulation is in the process until a certain termination condition is applicable. This section presents the simulation model, performance parameters and simulation procedure.

Table 1 Simulation Parameters

Parameter	Values
Length (l)	800m
Width (w)	800m
Depth (d)	800m
uw-nodes (n)	100
Communication range of uw-nodes N_{CR}	30m
Temperature	2 – 20°C
Communication range of AUVs AUV_{CR}	60m
No. of anchor nodes	10-20%
Transmission frequency T_f	24KHz
Attenuation (α)	0.01 – 1.0
SL	100 dB
δL	40m
k	1.5

A. Simulation Model

An area of 800m X 800m X 800m square meters is considered a monitored space for UAWSN. Acoustic nodes are randomly placed from 50 with a step of 10 to 100 in the 3D space. AUV is deployed initially at the AUV_d and travels on the linear trajectory. The broadcast interval point(δL) is set to 40m. The length of the linear trajectory is 800m, k = 1.5, SL = 100 dB. The few reference nodes are randomly deployed. A beacon message linearly moves at a velocity 1 m/s and broadcasts at an interval of 1s. The base/sink station is situated on the ocean bank.

B. Performance parameters

Localization ratio: It is the ratio of many localized nodes and the total number of nodes deployed in the network.

Energy consumption: This is the cumulative energy consumed for localization in one iteration/period. To achieve intensity I_t with transmitter power P_t at a distance of 1 meter from the source towards the direction of the receiver as per [18] is given in equation (6)

$$P_t = 2\pi * 1m * D * I_t \qquad (6)$$

in Watts, where D is the depth in meters and I_t is intensity.

Localization accuracy: This is the difference between the actual location and the calculated location. If $NE_{(x;y;z)}$ is the estimated location of an underwater sensor node and $NA_{(x;y;z)}$ is the actual location. The location accuracy is given in equation (7)

$$LE = \left|NE_{(x,y,z)} - NA_{(x,y,z)}\right| \qquad (7)$$

The average location error is given in equation (8)

$$LE_{avg} = \frac{1}{2}\sum_{i=1}^{n} LE_i \qquad (8)$$

The location error is crucial if it is above the given threshold.

Network lifetime: It is the number of times the overall localization process runs in the system until an energy level of underwater nodes below the given energy threshold. Find the nodes (m) whose energy level is larger than the node's energy threshold i.e. find the number of nodes (m) if$\left(T_{lifetime}(i) \leq E_{th}\right)$ for each node i in the network. To make the network connected, let P_N be the % of nodes that must be above the energy threshold.

$$N_{stable} = \frac{P_N}{100} * n \qquad (9)$$

If $(m \geq (n - N_{stable}))$, then the network fails, otherwise the localization process repeats after a certain condition is satisfied.

C. Simulation Procedure

The proposed scheme is simulated by using the input parameters (given in IV-B) until more than 50% of the initial nodes energy drains below the threshold. The algorithm 2 provides a simulation procedure's pseudo code.

Algorithm 2 Simulation procedure

```
function SIMULATION(O)
    Setup the network environment as given in III-A.
    Initialize agencies, knowledgebase
    Formation of trapezoids by TFA
    Defining the AUVs trajectory.
    while until termination condition satisfies do
        AUV travels on a defined trajectory
        AUV Broadcasts real-time location information.
        Anchor/reference nodes performs re-localization
        LA performs the localization in the trapezoid
        LA updates information onto knowledgebase
    end while
end function
```

V. RESULT ANALYSIS

In this section, the analysis of simulation results for various performance parameters is discussed.

The figure (8) shows the number of sensor nodes' impact on localization error. It is observed that the proposed algorithm produces minimum localization error even though by continuously increasing the number of nodes. An increase in number of sensor nodes consumes more power and reduces the location error. It is also seen that there is no much change in the location error if the number of nodes is increased beyond some limit. For a given area, in the proposed scheme we observed that an increase in nodes beyond the limit does not yield any better results. As shown in figure (9) localization ratio is dependent on the number of anchor nodes are deployed in the network. The localization ratio increases with an increase in anchor nodes. The proposed scheme shows that more un-localized nodes are localized with a higher percentage of localization ratio compared with another scheme.

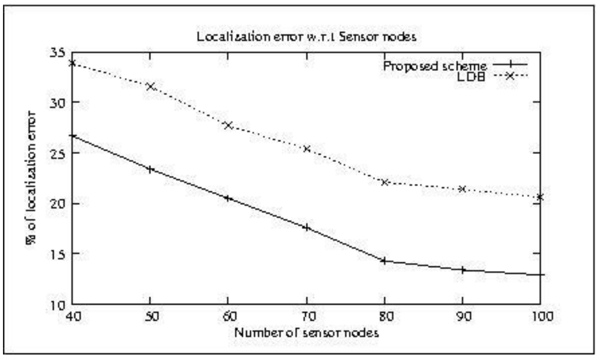

Fig. 8 Localization error

Many disjoint trapezoids are created and each anchor node is sharing common vertex with many trapezoids.

The proposed scheme requires less number of anchor nodes because each one is involving in the localization with its associated trapezoids. In some larger size trapezoids, it is difficult to localize un-localized nodes due to the unavailable communication of anchor nodes which reduces the localization ratio. In some cases, the anchor node is unable to communicate with the sensor nodes within the trapezoid due to unreachable or inactive state. However, the proposed scheme has a better localization ratio because of trapezoids and search data structure.

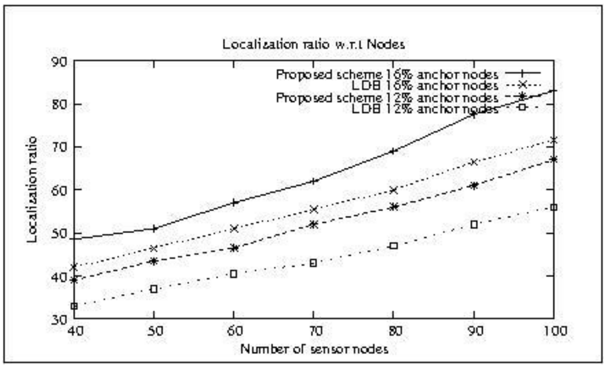

Fig. 9 Localization ratio

As shown in figure (10), the presented scheme consumes less energy in the case of fewer anchor nodes compared with other schemes. The proposed scheme consumes little more energy in case more anchor nodes are deployed because of redundant involvement of sensor nodes in the localization process when compared with other schemes. Nodes near to the surface are not stationary and need to be localized frequently which causes more consumption of energy. As AUV dives into deeper levels the nodes to be localized are less in number. The graph presents energy consumption at different levels with other schemes.

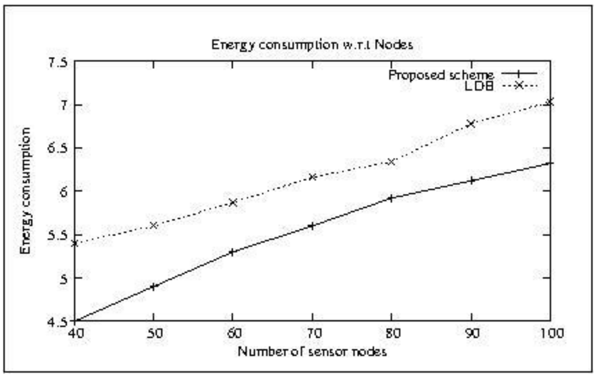

Fig. 10: Energy consumption

VI. CONCLUSION

The proposed localization scheme is presented in three major levels. In the first level, computational geometrical shapes are used to form trapezoids. The sink node initiated the trapezoid formation process before localization. The sink agency and anchor agency together have formed the different trapezoids and updated onto the node knowledge base (NKB) and sink knowledge base (SKB). While creating these trapezoids, TFA has also constructed the search data structure D. In the second level, AUV is deployed at different depth levels to follow the linear trajectory and broadcasts real-time beacon messages. The anchor nodes receive these messages and re-localize themselves and update the NKB and SKB. In the third level, Localization Agent performed the localization by using the search data structure and the trapezoid information. The proposed algorithm is developed using the search data structure which is efficient to search the trapezoids in very quick time by using binary search. Sink node can quickly localize the requested node’s location using this trapezoid structure than the other methods. Overall, the computational geometrical trapezoid approach for localization is novel and achieved good results. In this work, more numbers of trapezoids are created, that can be minimized in future work. The AUV trajectory may be considered based on the search data structure D instead of the linear trajectory. There is scope to design search data structure at every vertical slab of the targeted area. The number of anchor/reference nodes can be minimized in future work.

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AUTHORS PROFILE

B. S. Halakarnimath completed his B.E and M. Tech. in Computer Science & Engineering from VTU, Belagavi, Karnataka, India. Presently he is a VTU research scholar pursuing his Ph. D. under the guidance of Dr. A. V. Sutagundar, Basaveshwar Engineering College, Bagalkot, Karnataka, India. He has authored 1 book chapter and published 4 papers in conferences and journals. His research area is underwater acoustic wireless sensor networks, machine learning, and algorithms. He is a life member of IEI and ISTE organizations.

AUTHORS PROFILE

A. V. Sutagundar completed his B.E and M. Tech. in Electronics & Communication Engineering from VTU, Belagavi, Karnataka, India. He received his Ph. D. in 2013 from VTU, Belagavi, India. Presently he is working as an Associate Professor, Dept. of ECE, Basaveshwar Engineering College, Bagalkot, Karnataka, India. He has authored 8 book chapters and published more than 70 papers in international conferences and journals. His research area is IoT, wireless sensor networks, machine learning, and digital image processing.

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