Node Localization Performance for UWSN Topologies

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Abstract **—**The first and foremost task in an underwater sensor network is node deployment that provides good coverage for any number of Underwater Sensor Nodes (USNs). This paper studies the localization of sensor nodes for different node deployment techniques in a 3-D monitored space namely random deployment scheme, cube deployment scheme and regular tetrahedron deployment schemes are implemented for increasing localization ratio, decreasing localization error and to have good enough network connectivity.

Index Terms**—**Localization error, Localization ratio, Network connectivity, Non-localized nodes

I. Introduction

In recent days, UWSNs, find applications in resource exploration, target tracking, and pollution monitoring [1]-[3]. Underwater sensor networks are especially designed to ensure underwater implementations, whose excecution and functioning are based on acoustic quantification and sharing of information.

Different types of nodes can be employed in USNs based on the application e.g., surface sinks required for data acquisition namely GPS signal collecting area and underwater nodes interfaced with floating type anchor nodes.

These nodes can be deployed forming different topologies. The node deployment and its localization are difficult due to the movement of nodes because of movement of water currents, ships, fishes. Also, there will be localization error. This results in long transmission delay [4], [5]. Also, radio communication has power loss and bit error rate greater than acoustic communication. To overcome this, a efficient node deployment strategies are required. A 2-D environment was considered previously and algorithms developed. These focused mainly on number of sensors being deployed to be minimized.

A placement scheme of mobile data collectors in underwater acoustic sensor networks (UASNs) was proposed by Alsaiah *et al*. [6] Here, the surface data collectors used to gather information from the underwater sensors using optimal multi-hop routing track for transferring information to the sink which was present on-shore.

Nie *et al*. [7] proposed a technique to integrate UASNs with wireless communication networks. One such technique was surface gateway deployment. A two optimal routing algorithm was developed to achieve minimal delay and balanced energy usage for transmissions between the nodes.

A virtual sink architecture with mathematical analysis was proposed by Seah *et al*. [8] for multipath data delivery to sinks which was more reliable and energy efficient.

A 3D network for coverage and connectivity measurement was proposed by Alam *et al*. [9] where the main aim was to sense all the nodes in the network with the use of Voronoi tessellation.

In this work, the random, cube and the regular tetrahedron deployment schemes are studied for good localization performance.

The rest of the paper is arranged as follows: Section 2 deals with USN architecture, Section 3 deals with Implementation followed by simulation results, discussion and conclusion.

II. USN Architecture

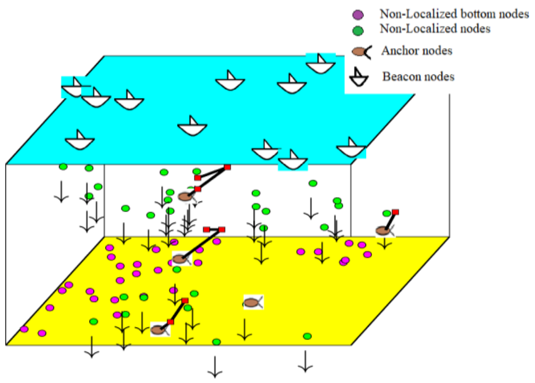

Fig. 1. 3-D USN architecture

A USN has tens to hundreds of sensor nodes with different capabilities deployed underwater with different strategies. A typical USN architecture is as shown in Fig. 1 having mainly three types of nodes.

1. Beacon nodes: These nodes know their exact positions and are always in contact with the external systems outside water environment to receive GPS co-ordinates regularly from the satellites. So, they are deployed on the water surface area. These nodes should travel from surface at regular intervals to broadcast their coordinates to the non-localized nodes which have sent location request message. These nodes consume more power but have high computing capability which consists of two transceivers for communicating efficiently.

2. Anchor nodes (Reference nodes): These nodes at different depths assist the beacon nodes in finding the

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location of non-localized node and consume less power compared to beacon nodes.

3. Non-localized nodes: These nodes are involved in data collection and processing. These nodes send localization request messages to the beacon nodes through anchor nodes or already localized nodes.

Two categories of non- localized nodes are considered, namely non-localized nodes which are present at the bottom area and the non-localized nodes which are present over the other areas.

III. Implementation

The Flow Diagram of Deployment schemes in USN for localization performance analysis is shown in Fig. 2.

The anchor and non-localized nodes are deployed using the three deployment schemes - random, cube and regular tetrahedron for performance evaluation considering localization ratio, localization error, average number of nodes communicating with the nearest neighbouring anchor nodes and overall network connectivity. Multilateration method is applied to the deployed nodes to find the co-ordinates of the non-localized nodes.

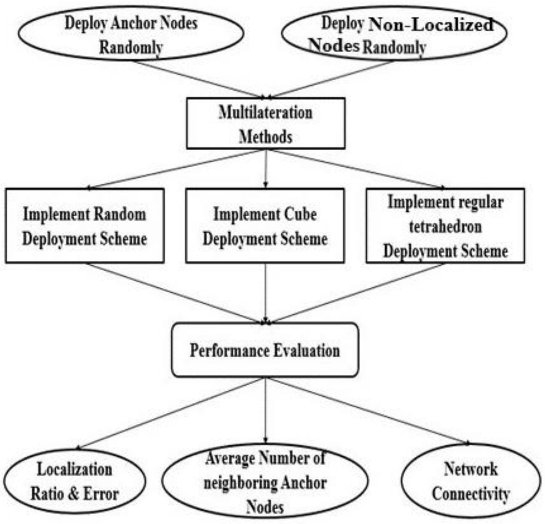
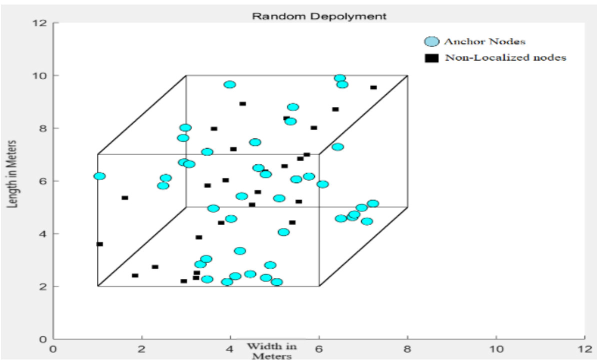


Fig. 2. Flow diagram

A. Random Deployment Scheme

The random deployment is the most commonly used strategy because of its simplicity. The scheme's network model and topology is as shown in Fig. 3.



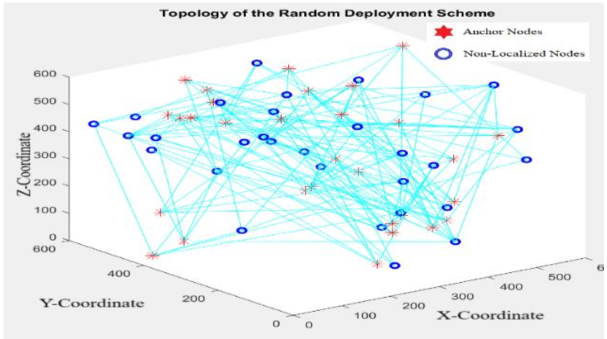


Fig. 3. Random deployment

In this scheme, anchor nodes and non-localized are randomly deployed in a 3-D monitored space. In this scheme, different issues such as partitioning of the network, non-uniform coverage in the network etc. are caused. Here, many of the edge nodes are isolated and they are less likely to get localized. Therefore, alternate deployment strategies such as cube and regular tetrahedron topologies are thought of.

B. Cube Deployment Scheme

The Cube Deployment scheme's network model and topology is as shown in Fig. 4.

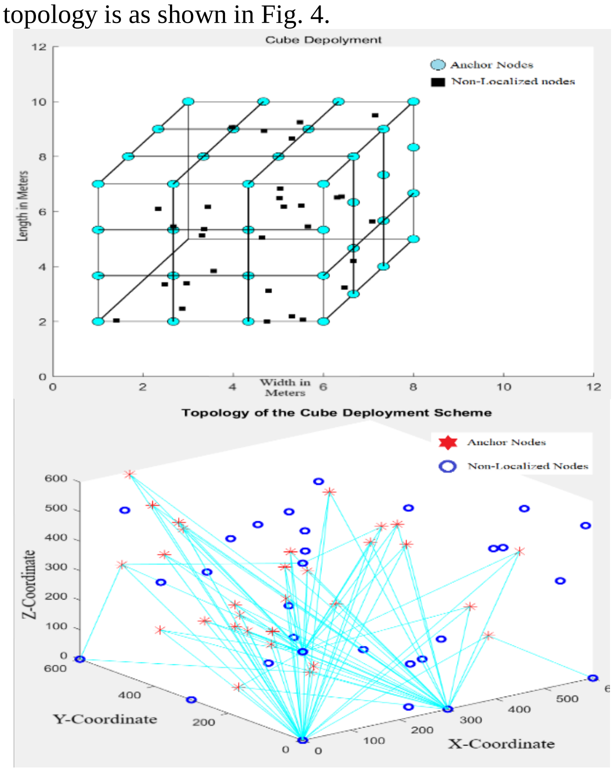


Fig. 4. Cube deployment

In cube deployment scheme, the anchor nodes are deployed at the vertices of the cube boundary and the non-localized nodes are deployed in random fashion inside the cube boundary. This scheme helps to restrict the sensor node deployment in a specified cube boundary so that the isolation beyond the boundary is overcome.

C. Regular Tetrahedron Deployment Scheme

The Regular Tetrahedron Deployment scheme's network model and topology is as shown in Fig. 5.

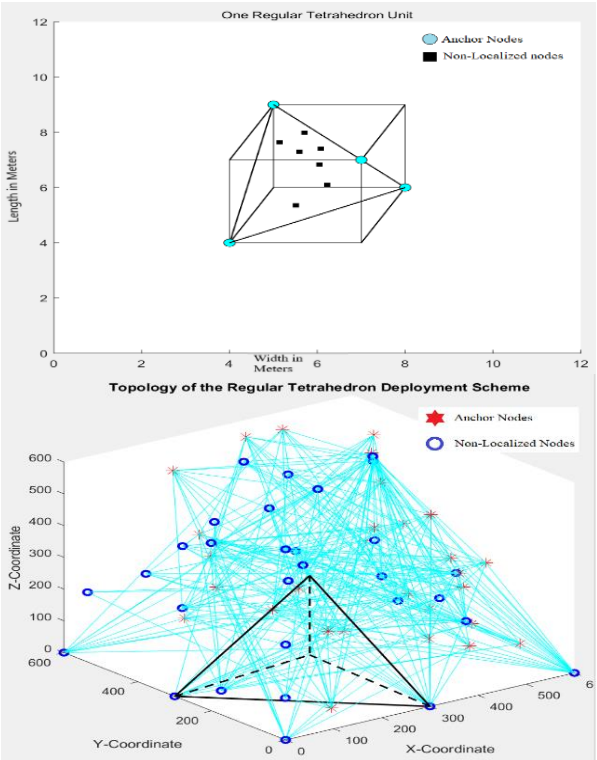


Fig. 5. Regular tetrahedron deployment

Here, the anchor nodes are deployed at the vertices of specified regular tetrahedrons boundary and the non-localized nodes are deployed in random fashion inside the regular tetrahedron boundary. Since the area of deployment is restricted to a small boundary compared to cube deployment there is less consumption of energy for the sensor nodes to communicate with each other.

The performance parameters such as localization ratio, localization error, average number of anchor node neighbours and overall network connectivity is evaluated using MATLAB.

IV. Results and Discussions

A 600m×600m×600m water environment is created using MATLAB for evaluating the three deployment schemes. An anchor node percentage of 5% and 10% are maintained for 100 to 400 sensor nodes with a step size of 50. The anchor nodes and sensor nodes are deployed depending on the deployment scheme in a 3-D environment. The different performance parameters are evaluated for the above three deployment schemes.

A. Localization Ratio

It is the ratio of the number of localized nodes N_l to the total number of non-localized nodes in the network N_t.

The localization ratio is calculated as follows [10]

$$LR = \frac{N_l}{N_t} \qquad (1)$$

Fig. 6 shows the variation of localization ratio in percentage to the total number of sensor nodes for the three deployment schemes. The regular tetrahedron deployment scheme performs better compared to the other two schemes with regard to localization ratio. At 5% anchor node percentage, the localization ratio of the random deployment scheme varies more compared to the cube deployment scheme and the regular tetrahedron deployment scheme. This is because edge nodes are isolated in random deployment scheme and so only limited number of coordinate messages is received from anchor nodes which helps in localization.

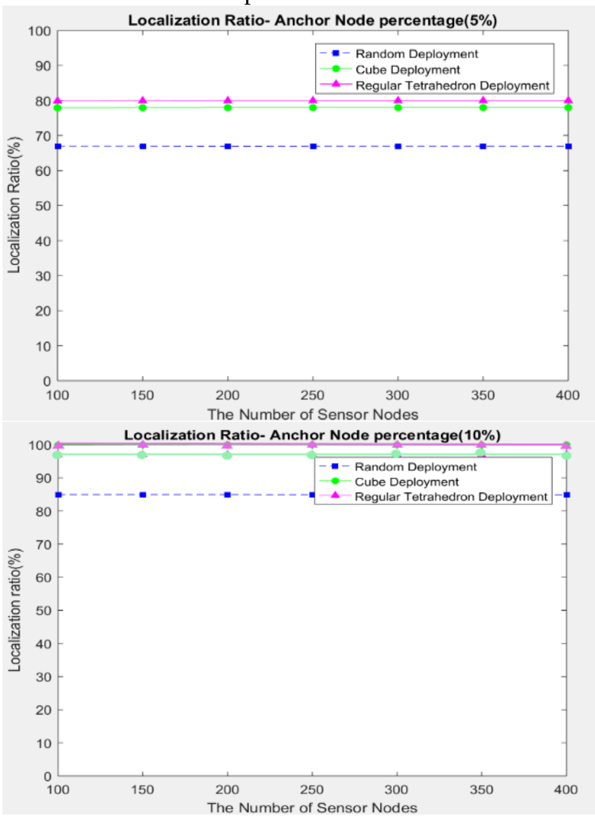


Fig. 6. Localization ratio

When the anchor node percentage is gradually increased, localization ratio increases in all the three schemes. Also, the cube deployment and the regular tetrahedron deployment scheme shows better performance. In random deployment, some of the nodes are isolated and cannot communicate with other sensor nodes or anchor nodes and are likely to be non-localized. Therefore, we obtain lower localization ratio. However, in cube and regular tetrahedron, probability of a non-localized node having a nearest neighbour is high resulting in high localization ratio.

B. Localization Error

Localization error is the difference between estimated co-ordinates and real co-ordinates measured in meters.

The localization error per localized node is calculated as follows [11]

$$L_{error} = \frac{\sum_{i=1}^{N_l} \sqrt{(u_i - x_i)^2 + (v_i - y_i)^2 + (w_i - z_i)^2}}{N_l} \qquad (2)$$

where (u_i, v_i, w_i) are real co-ordinates of a non-localized node i, (x_i, y_i, z_i) are estimated co-ordinates of a non-localized i, and N_l is the number of localized nodes.

Fig. 7 shows the relation between the localization error and the total number of sensor nodes in the network. It can be observed that the regular tetrahedron scheme has less localization error compared to the other two schemes irrespective of the anchor node percentage in the network.

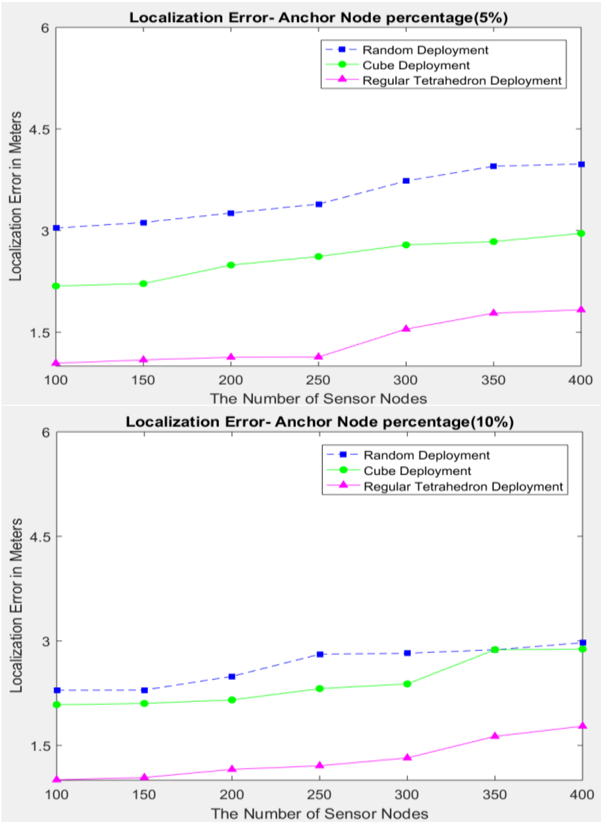


Fig. 7. Localization error

C. *Average Number of Anchor Node Neighbours*

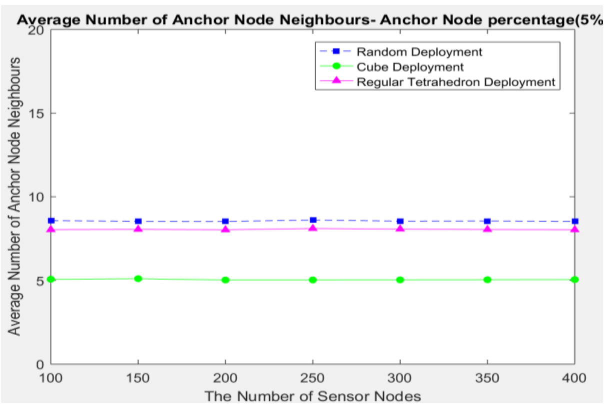
Average number of anchor node neighbours can be calculated as the ratio of the number of non-localized sensor nodes that can communicate and are nearer to anchor nodes N_{CA} to the total number of sensor nodes N_t.

The larger the average number of anchor node neighbours, the more options the non-localized nodes have to help them with localization.

The average number of anchor node neighbours can be calculated as follows [12]

$$N_{av} = \frac{N_{CA}}{N_t} \tag{3}$$

Fig. 8 shows the average number of anchor node neighbours available in the three schemes.



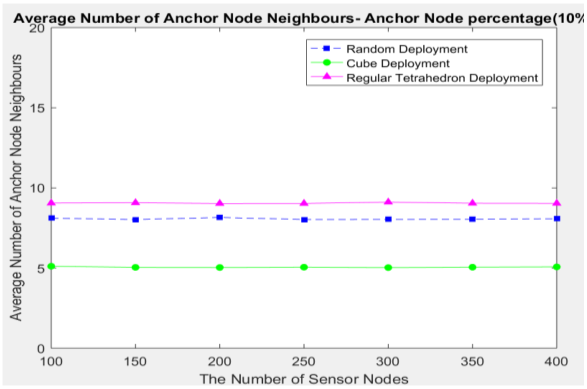


Fig. 8. Average number of anchor node neighbours

The regular tetrahedron deployment scheme and the random deployment scheme have a greater number of anchor node neighbours than the cube deployment scheme as the anchor node percentage increases. Here, the non-localized nodes in the regular tetrahedron deployment scheme will help for choosing appropriate anchor nodes to localize itself, which contributes to a lower localization error.

D. *Network Connectivity*

The ratio of the number of sensor nodes that can communicate with other sensor nodes N_{comm} to the total number of sensor nodes N_t is network connectivity.

The network connectivity can be calculated as follows [13]

$$NC = \frac{N_{comm}}{N_t} \quad (4)$$

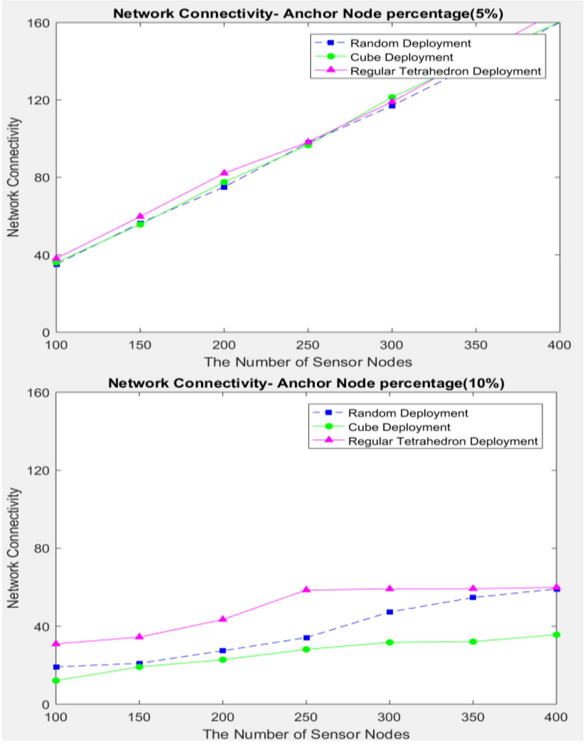


Fig. 9. Network connectivity

Fig. 9 shows the evaluation of the three deployment schemes with respect to network connectivity with anchor node percentages set to 5% and 10%.

The network connectivity observed with regular tetrahedron scheme is better as compared to the other two schemes as most of the sensor nodes have one hop neighbours.

V. Conclusions

The three deployment schemes namely random, cube and regular tetrahedron scheme is studied in 3-D monitored environment. The comparison of these three schemes in terms of localization ratio, localization error, average number of anchor node neighbours and network connectivity is evaluated using MATLAB. It is observed that by using the regular tetrahedron scheme there is increase in the localization ratio and decrease in the localization error. The network connectivity will get strong as the number of anchor node neighbours increases and also when there is an increase in the network node density.

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