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Significance of Node Deployment Strategies on Localization Performance in Underwater Acoustic Sensor Networks

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***Abstract*—**Localization is one of the fundamental tasks for Underwater Acoustic Sensor Networks (UASNs) which is required for data tagging, node tracking, target detection, and it can be used for improving the performance of medium access and network protocols. When setting up an UASN, node deployment is the first and foremost task, upon which many fundamental network services, such as network topology control, routing, and boundary detection. This paper aims at analyzing the impacts of node deployment strategies on localization performances in a 3-D environment. We propose three node deployment schemes such as Alternate Cubic (Alt-CB), Truncated Octahedron (TO), Alternate Hexagonal Prism (Alt-HP). Simulation results shows that the Alt-HP deployment scheme outperforms the random and other node deployment schemes in terms of reducing localization error and increasing localization ratio while maintaining the average number of neighbouring anchor nodes and network connectivity.

***Keywords*—**Localization performance, node deployment, underwater acoustic sensor networks (UASNs)

I. Introduction

UASN technology provides new opportunities to explore the oceans, and consequently it improves our understanding of the environmental issues, such as the climate change, the life of ocean animals and the variations in the population of coral reefs. Additionally, UASNs can enhance the underwater warfare capabilities of the naval forces since they can be used for surveillance, submarine detection, mine countermeasure missions and unmanned operations in the enemy fields. UASNs are wireless sensor networks (WSNs) specially designed in aqueous environments for underwater applications, whose implementations and operations are solely based on acoustic measurements and communications [1].

Localization generally requires several objects with known locations (anchors) and distance or angle measurements between these anchors and the object to be localized (unknown node). There are various methods to provide location information for the anchors. Anchors may be placed at fixed locations and their coordinates may have been pre-configured, or they may have special hardware to learn their locations from a location server, such as the Global Positioning System (GPS). For estimating the location of an unknown node, traditional localization methods generally use distance or angle measurements between the anchor and the unknown node or a combination of the two measurements. In a WSN, angle and distance measurements can be collected by one of the following methods: *i*) Received Signal Strength Indicator (RSSI), *ii*) Angle-of-Arrival (AoA), *iii*) Time Difference of Arrival (TDoA), *iv*) Time of Arrival (ToA).

UASNs are deployed in a 3-D environment, which inevitably brings on new challenges, such as long transmission delay, node mobility caused by water currents. When setting up an UASN, node deployment is the first and foremost task, since it provides fundamental support for many network services, such as network topology control, routing, and boundary detection [11]. In particular, since underwater and bottom nodes transmit the sensing information to surface sinks in a multihop manner, a good deployment strategy will promise network connectivity and provide a stable network topology for the fulfillment of subsequent monitoring tasks. Prominent examples include large-scale short-term and distributed data acquisition networks meant for time-critical aquatic applications, where designing a suitable deployment strategy is a basic and must-do task to provide support for network topology control, data collection, etc. Localization is a process of finding such location information of the sensor nodes in a given coordinate system. To localize a UASN in the global coordinate system, some special nodes should be aware of their positions in advance either from an external GPS or its own memory (initialized during manual placement); such nodes are called anchor nodes (or beacon nodes). Other sensor nodes, which are usually called ordinary nodes (or unknown nodes), calculate their positions by using some localization algorithms.

This paper investigates the impacts of different deployment schemes on the localization performances, such as localization error, localization ratio, average number of neighboring anchor nodes, and network connectivity, in 3-D UASNs. The simulation conducted in this paper reveal that the Alt-HP deployment scheme outperforms than the random and other node deployment schemes in terms of reducing localization error and increasing localization ratiowhile maintaining the average number of neighboring anchor nodes and network connectivity.

The rest of the paper is organized as follows. In Section II, summarized the existing work. In Section III describes proposed method. Section IV presents a detailed analysis of simulation results. Finally, in Section V, makes conclusion.

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II. EXISTING WORK

Extensive research has focused on node deployment algorithms in UASNs, the majority of which aim at achieving high network connectivity and coverage, minimizing the number of sensor nodes and their energy consumption, or improving data delivery ratio.

Guangjie et al. [2]analysed the impacts of node deployment strategies on localization performance in UASN. They analysed localization performances in 3-D UASNs, more specifically, the random deployment scheme, the cube deployment scheme, and the regular tetrahedron deployment scheme. They were not analysed the node deployment scheme such as Alt-CB, TO and Alt-HP.

Alam et al. [5] investigated the maximal coverage and connectivity issues in 3-D networks with the least number of sensor nodes to be deployed in the monitored space. The authors defined a metric called volumetric quotient, which is a metric of the quality of the competing space-filling polyhedrons.They compared volumetric quotients of truncated octahedron cells, hexagonal prism cells, rhombic dodecahedron cells, and cube cells. The results indicated that the use of the Voronoi tessellation to create truncated octahedral cells achieves the best results. In a separate study, Alam et al. [6] assumed that nodes are uniformly and densely deployed in a 3-D space. They divided the 3-D space into cells, in each of which, only one node is active at any given time to minimize the number of active nodes while maintaining the full coverage and connectivity.Results showed that the number of active nodes can be minimized if the shape of each cell is a truncated octahedron and the sensing range is at least 0.52325 times the transmission range. Thus, the truncated octahedron model has the highest network lifetime.

This paper aims at analysing the impacts of four deployment schemes on localization performances in 3-D UASNs, more specifically, the random deployment scheme, the alternate cubic (Alt-CB) deployment scheme, the truncated octahedron (TO) deployment scheme, and the alternate hexagonal prism (Alt-HP), where sensor nodes may be deployed at different depths depending on the deployment strategies. For the four aforementioned schemes, we will examine parameters such as localization error, localization ratio, average number of neighbouring anchor nodes, and network connectivity. The conducted simulations show that the alternate hexagonal prism deployment scheme can achieve higher localization accuracy while maintaining good localization ratio, the average number of sensor nodes, and network connectivity.

III. PROPOSED METHOD

In this section, we illustrate the proposed node deployment schemes such as alternate cubic (Alt-CB), truncated octahedron (TO), and alternate hexagonal prism (Alt-HP) in 3-D monitored region. In random deployment scheme, anchor nodes are deployed at the vertices of the prepositioned space-filling cubes, where as in Alt-CB, TO and Alt-HP deployment scheme, anchor nodes are deployed at the vertices. Ordinary nodes in all the four deployment schemes above are deployed randomly in the 3-D monitored space.

Parameter Settings and Performance Evaluation Criteria for the proposed model are listed below:

The deployment schemes are evaluated using MATLAB in a 800 m ×800 m ×800 m monitored space. The total number of sensor nodes varies from 150 with a step size of 50 to 400 while keeping the number of anchor nodes the same. As aforementioned, anchor nodes are deployed at the vertices of each polyhedron unit, and ordinary nodes are deployed randomly in the 3-D monitored space. Both anchor nodes and ordinary nodes can adjust their pumps to float at different depths. The scenarios when the anchor node percentage are, respectively, 6.75%, 16%, and 20% are considered in our simulations. The network topologies of three deployment schemes are depicted in Figs.1-4, respectively, where red dots represent anchor nodes, and blue circles represent ordinary nodes.

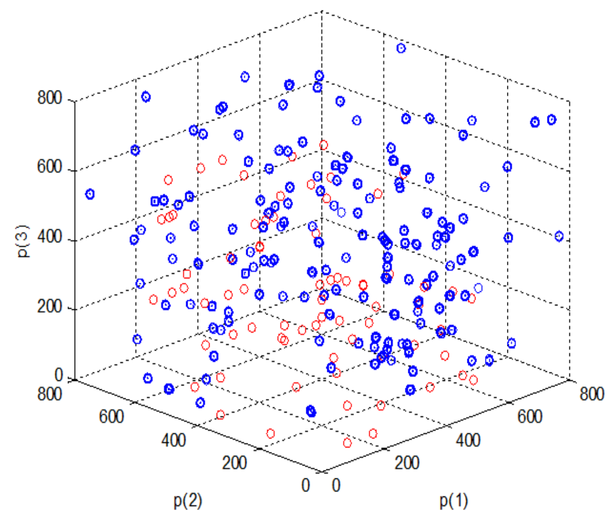

Fig.1 Topology of the random deployment scheme

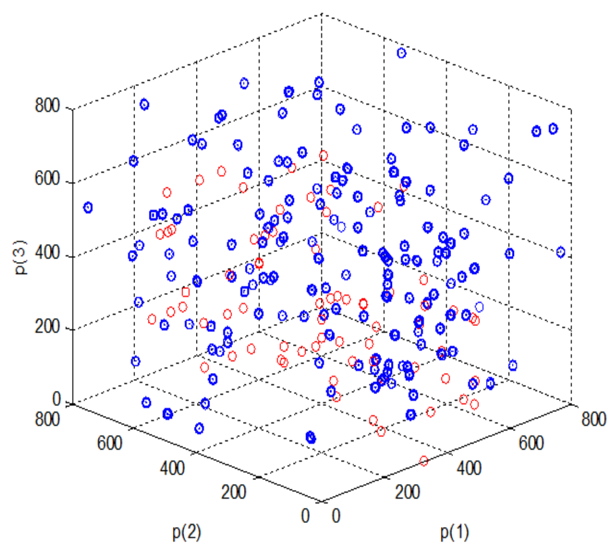

Fig.2 Topology of the alternate hexagonal prismdeployment scheme

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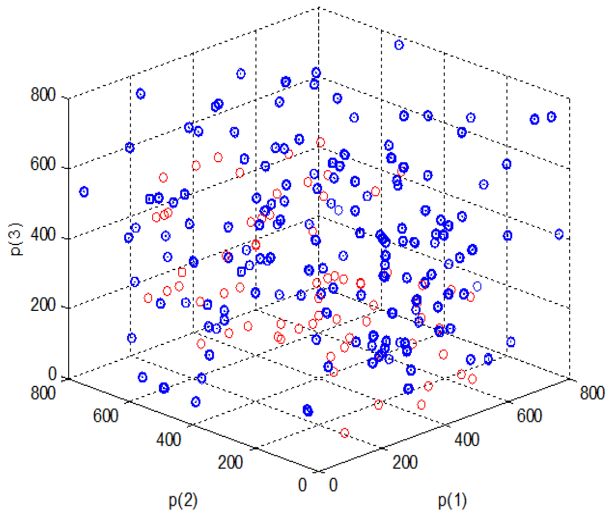


Fig.3 Topology of Alternate cubic deployment scheme

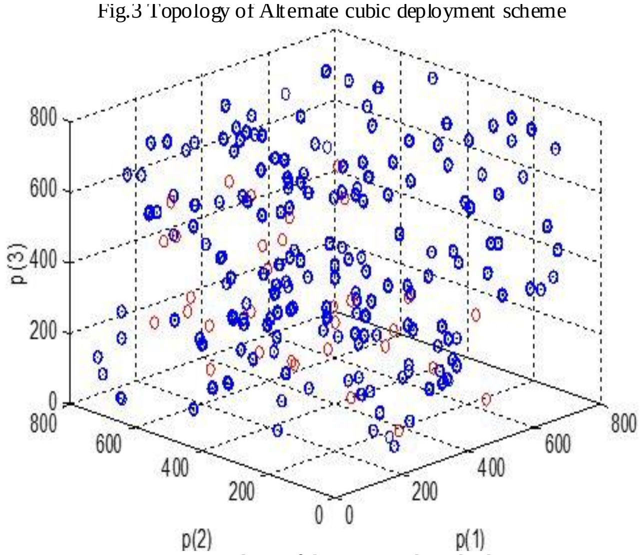


Fig.4 Topology of the truncated octahedron

The performances of the three deployment schemes are evaluated according to the following four criteria: localization ratio, localization error, average number of neighboring anchor nodes, and network connectivity, defined as follows.

- Localization ratio is the ratio of the number of localized ordinary nodes to the total number of ordinary nodes. Obviously, the higher the localization ratio is, the more ordinary nodes can be localized. The localization ratio can be computed as follows

$$L\_ratio = \frac{Nl}{No}$$

Where Nl is the number of localized ordinary nodes, and No is the total number of ordinary nodes.

- Localization error is the average distance between the estimated coordinates and the real coordinates. Clearly, the smaller the localization error is, the better the localization result will be. The localization error can be computed as follows [24]:

$$L\_error = \frac{\sum_{i=1}^{Nl} \sqrt{(u_i - x_i)^2 + (v_i - y_i)^2 + (w_i - z_i)^2}}{N_l}$$

where (ui, vi, wi) are real coordinates of an ordinary node i, (xi, yi, zi) are estimated coordinates of an ordinary node i, and Nl is the number of localized ordinary nodes

- Average number of neighboring anchor nodes is the ratio of the number of sensor nodes that can communicate with anchor nodes to the total number of sensor nodes. The larger the average number of neighboring anchor nodes is, the more choices the ordinary node will have to select appropriate anchor nodes to help with localization. The average number of neighboring anchor nodes can be computed as follows [25]:

$$A\_anchor = \frac{Ncom\_a}{N}$$

where $Ncom\_a$ is the number of sensor nodes that can communicate with anchor nodes, and N is the total number of sensor nodes.

- Network connectivity is the ratio of the number of sensor nodes that can communicate with other sensor nodes to the total number of sensor nodes, which can be computed as follows [26]:

$$N\_connectivity = \frac{Ncom}{N}$$

where $Ncom$ is the number of sensor nodes that can communicate with other sensor nodes, and N is the total number of sensor nodes.

IV. SIMULATIONS

1) *Localization Ratio:* Fig. 5 depicts the relationship between the localization ratio and the number of sensor nodes. Fig. 5(a) shows that the alternate hexagonal prism has more localization ratio compare to Alt-CB, TO and random. Fig. 5(b) and (c) shows that alternate hexagonal prism and truncated octahedron have greater localization ratio compare to Alt-CB and random.

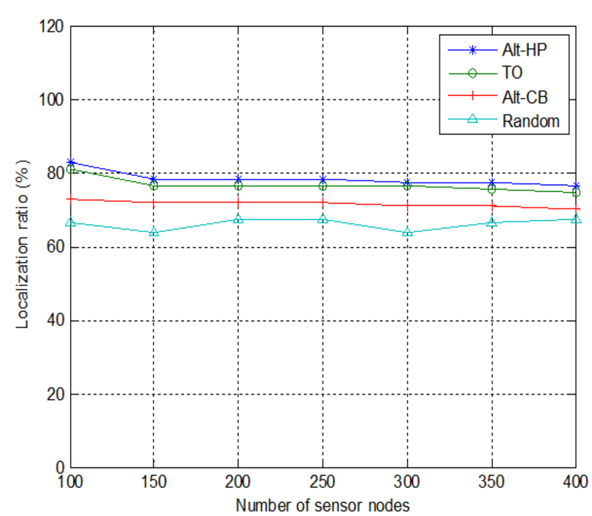


Fig.5. Localization ratio (a) Anchor node (6.75%)

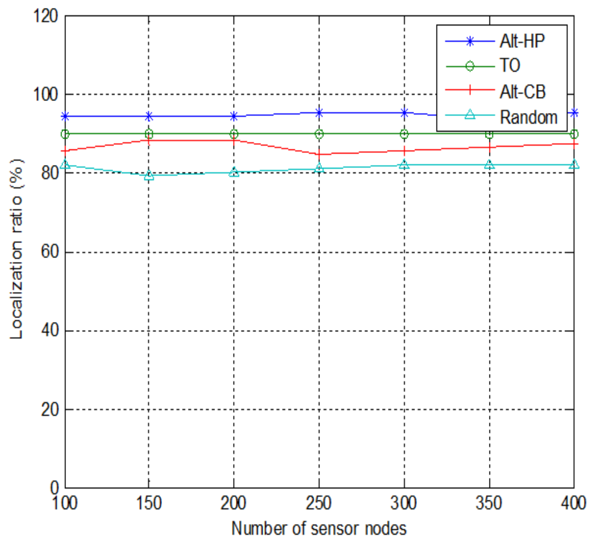


Fig.5. Localization ratio (b) Anchor node (16%)

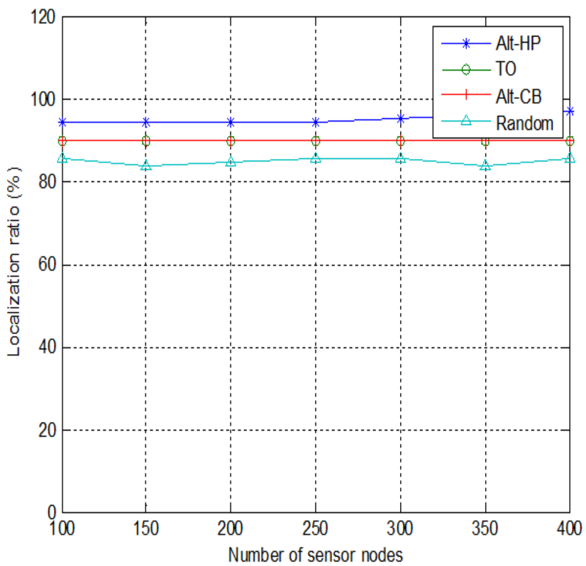


Fig.5. Localization ratio (c) Anchor node (20%)

2) *Localization Error:* Reducing the localization error of UASNs is one of the main motivations of this paper. Fig. 6 plots the relationship between the localization error and the number of sensor nodes.Fig. 6(a) shows that the alternate hexagonal prism has less localization error compare to Alt-CB, TO and random. Fig. 6(b)shows that alternate hexagonal prism and truncated octahedron have lesser localization error compare to Alt-CB and random. Fig. 6(c) shows that all the node deployment scheme have similar localization error, but alternate hexagonal prism outperforms.

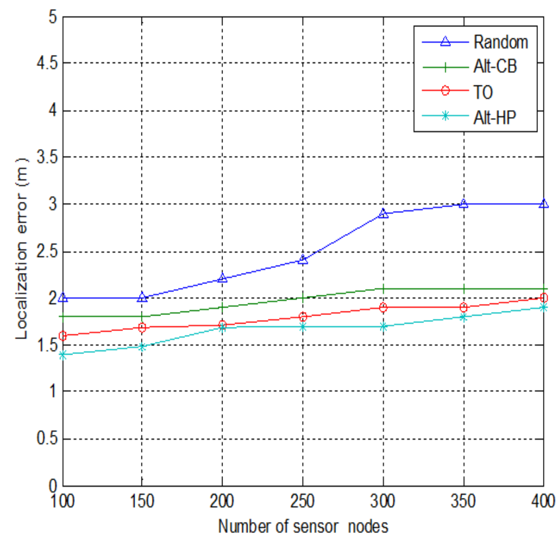


Fig.6. Localization error (a) Anchor node (6.75%)

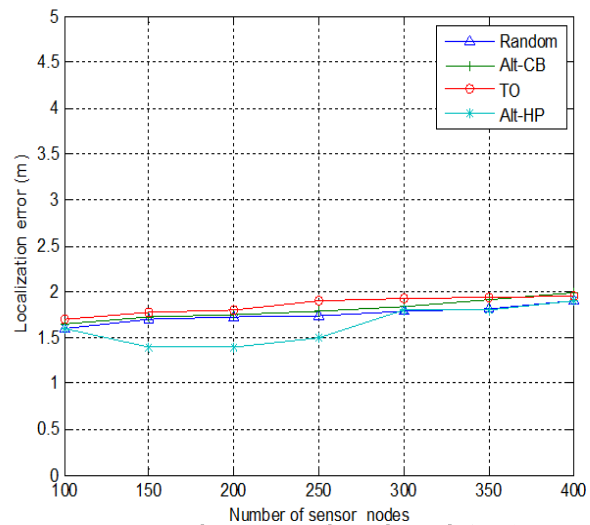


Fig.6. Localization error (b) Anchor node (16%)

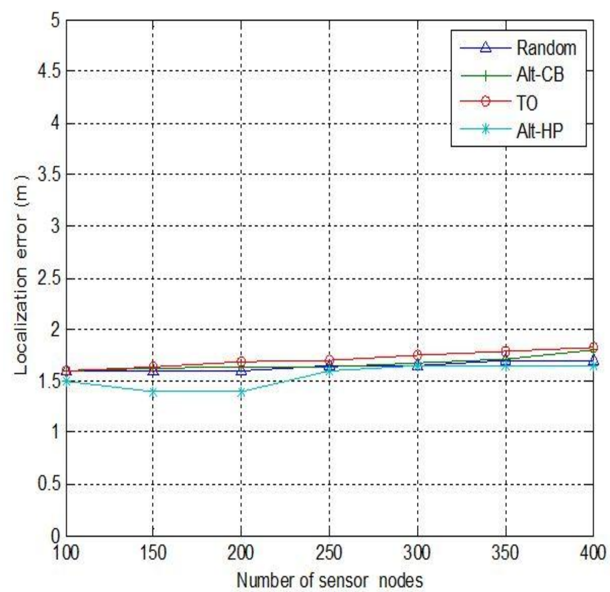
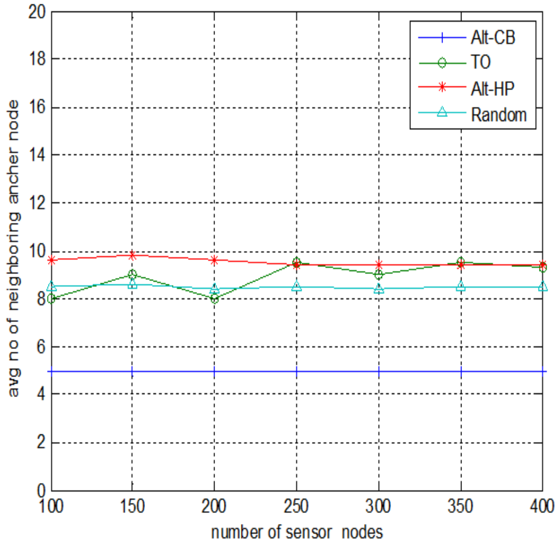
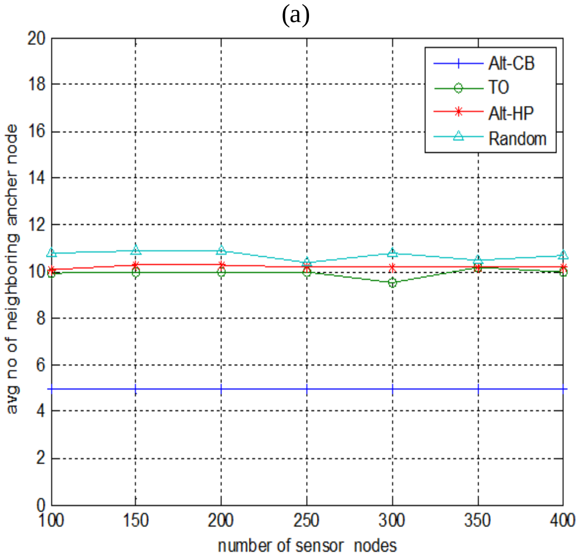


Fig.6. Localization error (c) Anchor node (20%)

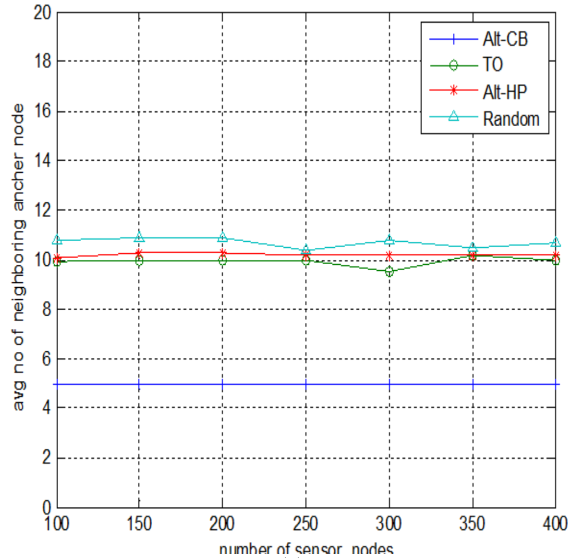
3) *Average Number of Neighboring Anchor Nodes:* Fig. 7 shows the average number of neighboring anchor nodesof the three deployment schemes with different numbers ofsensor nodes. Fig. 7(a) shows that the alternate hexagonal prism has the more number of neighboring anchor nodes. Fig. 7(b) and 7(c) shows that the alternate hexagonal prism and truncated octahedron have similar curves, because the anchor node percentage is vary with 4% only. Thus alternate hexagonal prism has greater in average number of neighboring anchor nodes.



(a)



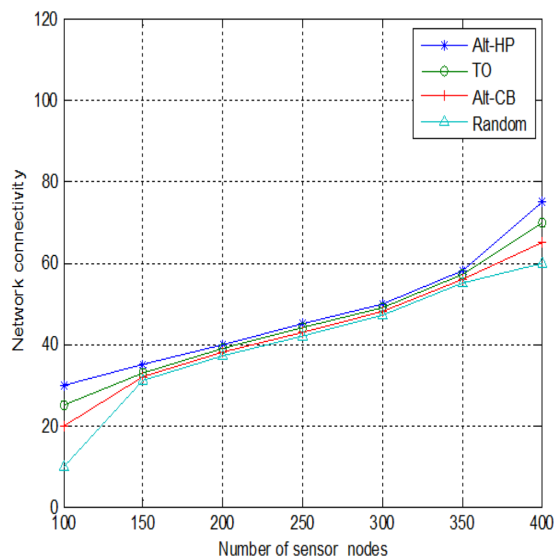
(b)



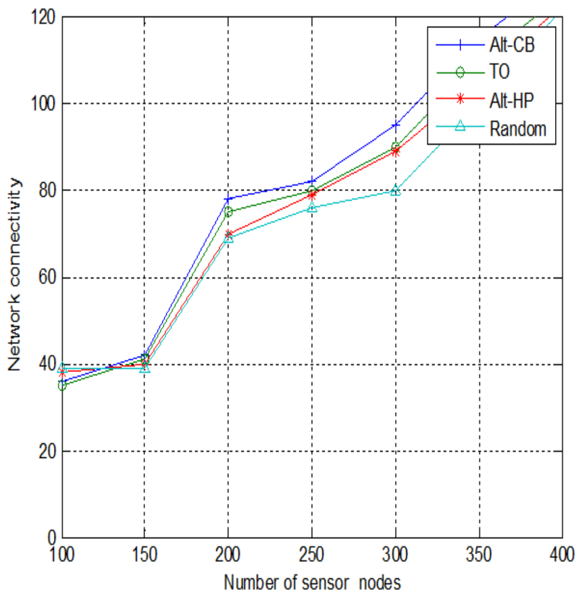
(c)

Fig.7. Average number of neighbouring Anchor Nodes (a) Anchor node (6.75%) (b) Anchor node (16%) (c) Anchor node (20%).

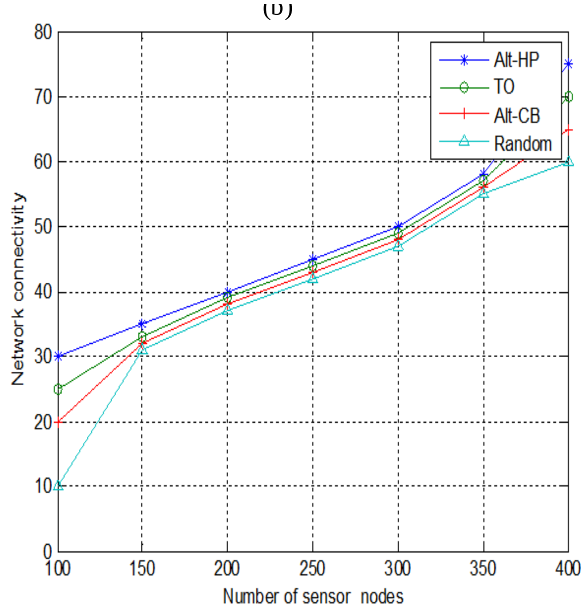
4) *Network Connectivity:* A lack of network connectivity may lead to an undesirable network fragmentation: isolated subnetworks may not be able to pass the information to the sinks, particularly in sparsely deployed UASNs. Fig. 8 examines the performances of the three deployment schemes in terms of network connectivity with different numbers of sensor nodes and anchor node percentages. Fig. 8(a), (b) and (c) shows that the network connectivity for alternate hexagonal prism is constant. Thus Alt-HP has better network connectivity.



(a)



(b)



(c)

Fig.8. Network Connectivity (a) Anchor node (6.75%) (b) Anchor node (16%) (c) Anchor node (20%)

V. CONCLUSIONS

In this paper, We proposed three deployment schemes in 3-D UASNs (the random deployment, Alt-CB, TO, Alt-HP deployment schemes) and compare their performances in detail in terms of localization ratio, localization error, average number of neighboring anchor nodes, and network connectivity. Confirming that the common belief that appropriately chosen node deployment strategy is of central importance for accurate localizations in UASNs, the simulations conducted in this paper revealed that the Alt-HP deployment scheme outperforms the other three schemes in terms of reducing localization error and increasing localization ratio, while maintaining the average number of neighboring anchor nodes and a reasonable network connectivity.

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