International Journal of Advanced Science and Technology
Vol. 4, March, 2009

A Localization Scheme for Underwater Wireless Sensor Networks

Kai Chen[1], Yi Zhou[2], Jianhua He[3]
[1]*School of Information Security and Engineering, Shanghai Jiaotong University, China*
[2]*School of Electronic, Information and Electrical Engineering, Shanghai Jiaotong University, China*
[3]*Institute of Advanced Telecommunications, Swansea University, UK*
* *Corresponding author: Kai Chen, kchen@sjtu.edu.cn*

Abstract

In this paper, we study the localization problem in large-scale Underwater Wireless Sensor Networks (UWSNs). Unlike in the terrestrial positioning, the global positioning system (GPS) can not work efficiently underwater. The limited bandwidth, the severely impaired channel and the cost of underwater equipment all makes the localization problem very challenging. Most current localization schemes are not well suitable for deep underwater environment. We propose a hierarchical localization scheme to address the challenging problems. The new scheme mainly consists of four types of nodes, which are surface buoys, Detachable Elevator Transceivers (DETs), anchor nodes and ordinary nodes. Surface buoy is assumed to be equipped with GPS on the water surface. A DET is attached to a surface buoy and can rise and down to broadcast its position. The anchor nodes can compute their positions based on the position information from the DETs and the measurements of distance to the DETs. The hierarchical localization scheme is scalable, and can be used to make balances on the cost and localization accuracy. Initial simulation results show the advantages of our proposed scheme.

1. Introduction

In recent several years, there has been a rapidly growing interest in Underwater Wireless Sensor Networks (UWSNs). UWSNs can be used for a broad range scientific exploration, including ocean sampling, environmental monitoring, undersea Explorations, disaster prevention, assisted navigation, distributed Tactical Surveillance and mine reconnaissance [1]. There are still many issues unsolved for the large scale UWSNs, such as reliable transport, routing, MAC and localization [2] [3] [4] [5] [6] because of the limited bandwidth, and high and variable propagation delays, severely impaired underwater channel, limited battery power.

In those general wireless sensor networks and applications, as well as the source detection and tracking applications of our interest, location estimation is a vital component. Without the node location information, the data received in the sink node can not be identified where it comes from, and becomes meaningless to the applications such as source tracking. In addition,

location information can be used to design efficient networking and management protocols. With regard to the mechanisms used for location estimation, localization algorithms can be divided into two major categories, range-based and range-free. In the range-based location algorithms, distance or angle estimates with neighbors will be used for calculating node locations. Typical range-based algorithms include the sum-distances based algorithm [14] [15]. In the range-free location algorithms, the neighbor distance/angle information is assumed to be unavailable for positioning due to the cost and hardware limitation. DV-hop algorithm is a typical range-free location algorithm [12] [13]. However, as mentioned above, the acoustic channel is severely impaired and the GPS signal can't propagate far through water, the existing positioning schemes for terrestrial WSNs can not be used directly for UWSNs. There are several localization schemes proposed for UWSNs [7] [8] [11]. In [7], a hierarchical localization scheme for large scale UWSNs was proposed. The system mainly consists of three types of nodes: surface buoys, anchor nodes and ordinary sensor nodes. The buoys are equipped with GPSs. The first localization step is anchor node localization, for which it is assumed all the anchor nodes can estimate their positions by contacting directly with surface buoys. The second step is ordinary node localization through anchor node's position information. The key of the scheme is that anchor nodes are localized through buoys. However, it can be very difficult for buoys to communicate directly with anchor nodes under deep water. On the other hand, a very large number of anchor nodes are used in [7], which results in very high cost and the localization performance is not satisfying. In [11], an interesting idea of Dive and Rise (DNR) positioning is presented. Mobile DNR beacons are used to replace static anchor nodes. Each DNR beacon is equipped with GPS. When DNR beacon move to water surface, they acquire x-y coordinate through GPS, and move down to broadcast their position to help localize ordinary sensor nodes. The major drawback of the DNR scheme is the high expense of the DNR beacons. There are 25 DNR beacons for only 1km x 1km x 1km underwater area, so 25 GPS and 25 moving equipments will be needed, which is very expensive. And the ordinary sensor nodes can only use the position information of DNR beacons to calculate their positions, which will degrade the localization performances.

In this paper, we are motivated to propose a hierarchical localization scheme for large scale UWSNs. The new scheme mainly consists of four types of nodes, which are surface buoys, DETs, anchor nodes and ordinary nodes. Surface buoy is assumed to be equipped with GPS on the water surface. A DET is attached to a surface buoy and can rise and down to broadcast its position. The anchor nodes can compute their positions based on the position information from the DETs and the measurements of distance to the DETs. Through the hierarchical design, we can achieve scalability, and make balances on the cost and localization accuracy. Initial simulation results show the advantages of our proposed scheme. In the rest of the paper, we will introduce our proposed localization in Section II. Simulation setting and result analysis are given in Section III. Finally Section IV concludes the paper.

2. The proposed hierarchy localization scheme

2.1. Network architecture

So far, there is not a very good solution for large scale UWSN localization in deep water. We are motivated to propose a new DET based hierarchical localization scheme. The new scheme will inherit the merits of DNR scheme, such as simplicity and high localization ratio, but can significantly decrease cost of the system, and increase scalability and localization performances thanks to the hierarchical design. The hierarchical network architecture is shown in Fig.1. It is compose of four types of nodes: the surface buoys, the DETs, anchor nodes and ordinary sensor nodes. We assume that all the underwater nodes are equipped with pressure sensors, which can provide the depth (z coordinate) information for the nodes. We also assume the network is static. But it is noted that the proposed scheme can be extended easily for non-static networks.

Next we will describe the functions of the nodes in details.

• Surface buoys: A number of Surface buoys are placed on the water surface. The surface buoys are equipped with GPS to obtain exact positions. The buoy will keep fixed and can play some important roles, such as navigation guidance. The buoys will be expense, but can be reused to provide position information in our proposed scheme for the DET attached to it, when the DET rises to the surface. It is not necessary for the DET and the surface buoy to communicate by acoustic transceiver.

- DETs: A DET is mainly composed of an elevator and an acoustic transceiver. The elevator helps the DET rise or dive in vertical underwater, and the transceiver communicates with the anchor nodes at different depths. We use a small number of surface buoys [10] with GPSs. Each buoy is equiped with a DET, which will be used to localize static anchor nodes. We assume that the DET can move in vertical underwater, for example, operate as the DNR beacon [10]. The DET get x-y coordinate from its buoy when it moves to water surface and links to its buoy, then moves down to broadcast position information at some pre-configured depths. For example, if the sensor network monitoring task is at the depth from 3km to 4km, the DETs can start broadcasting at 3km depth and continue broadcasting every 200m until it dives to 4km.
- Anchor nodes: The main task of anchor nodes is to help locate the ordinary sensor nodes. They will have more energy and use acoustic transceiver to communicate with the DETs. It will listen to broadcast messages from DETs and has larger communications range, if compared to the ordinary sensor nodes. Once a anchor node receives position messages from more than 3 DETs, it can calculate its coordinates. A localization confidence threshold will be used to check if the position estimation is satisfying. If the estimation is accepted, the anchor node will broadcast its position to help locate the ordinary sensor nodes sometime later.
- Ordinary sensor nodes: The ordinary sensor nodes will mainly be used for the sensing task. The ordinary sensor nodes are assumed to have less battery energy, and their acoustic transceiver will be switched off for the concern of saving energy. The ordinary sensor nodes with unknown positions will listen to broadcast messages periodically from the anchor nodes. If more than 3 broadcast messages are received from different anchor nodes, the ordinary sensor nodes will start to calculate its own position.

It is expected that the proposed scheme will have good scalability and localization performances, and can be used in a wide range of network scenarios. We will investigate later how the numbers of buoys, anchor nodes, and ordinary sensor nodes, and the communication ranges will affect the localization performances under different network settings.

2.2. Computation of node positions

Once the anchor nodes or the ordinary sensor nodes received more than 3 broadcast messages from different nodes, they can start to calculate their positions. As we have assumed that the z-coordinate of the nodes can be obtained by pressure sensors, the computation of node position is a 2-dimension positioning problem. Generally nodes can determine their positions based on the distance estimates by lateration, as used in [12] [13] [15]. A much simpler method, call Min-max, is used in [14]. In both cases no additional communications will be need for the determination of the node positions.

- Lateration: Lateration is a form of triangulation and is the most common method for deriving a position. For example, assume there are n anchors. For an ordinary sensor node with estimated distances (d_i) to the anchor i and it position (x_i, y_i), $i \in [1, n]$, the system of equations can be linearized and shown in [15] with the form $Ax = b$. For the node position (x, y), The equations can be solved by a standard least-squares approach: $\hat{x} = (A^T A)^{-1} A^T b$.
- Min-max: Lateration is quite expensive in the number of required floating point for computation limited wireless sensor networks. A much simpler method has been proposed by Savvides et al. in [14]. The main idea is to construct a bounding box for each anchor using the anchor's position and estimated distances, and then to determine the intersection of these boxes [15].

Both of the above methods can be used in our proposed hierarchical localization scheme. But in our experiments, we only tested the lateration based method.

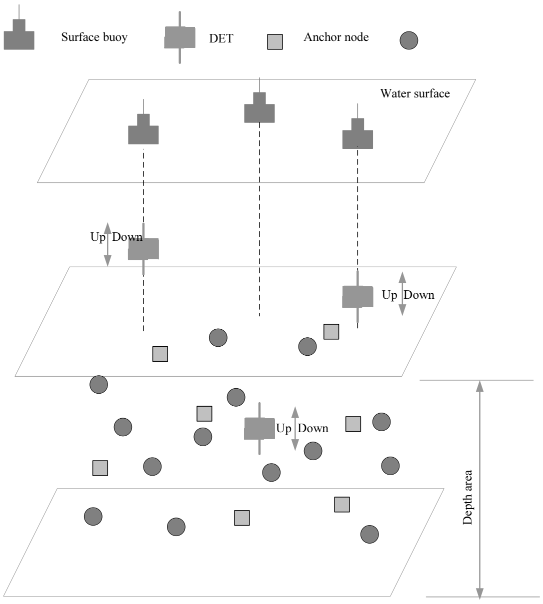

Figure 1. System architecture

3. Simulation results

3.1. Simulation settings

We have implemented our proposed scheme in Matlab to evaluate its localization performances. In our simulation experiments, the anchor nodes and the ordinary sensor nodes are assumed to be static. The water currents and the drifts are not considered. The anchor nodes and the ordinary sensor nodes are distributed randomly in 1km x 1km plane area and the underwater depth is from 3km to 4km. Therefore the whole investigated underwater area is is 1km x 1km x 1km. The number of the underwater sensor nodes (including the anchor nodes) vary from 100 to 500. The anchor nodes have the communication ranges from 250m to 400m. The percentage of anchor nodes varies from 15%, 20%, 25%, to 30% in our simulation. The measured distance between nodes is assumed to follow normal distributions with real distances as mean values and standard deviations to be one percent of real distances. The normal distributions distance error is used in many solutions [7] [9] [10]. For the page limit we only show results of the 300m and 400m transmission range.

We use only 3 buoys equipped with GPS, which are placed in fixed positions on the water surface. Each buoy is attached by a DET. The DET uses the acoustic transceiver to communicate with anchor nodes, with a configured communication range of 1 km in order that the 3 DETs can locate all the anchors in the 1km x 1km plane area. After these DETs acquire their x-y positions from buoys on the surface, they move in vertical and broadcast their positions information at every configured depth interval less than 1km starting from the depth of 3 km. All the nodes underwater have pressure sensor which provides depth (z coordinate), so the nodes can start to estimate their positions with three different position broadcast information. The anchor nodes and the ordinary sensor nodes calculate their x-y coordinates by lateration based method.

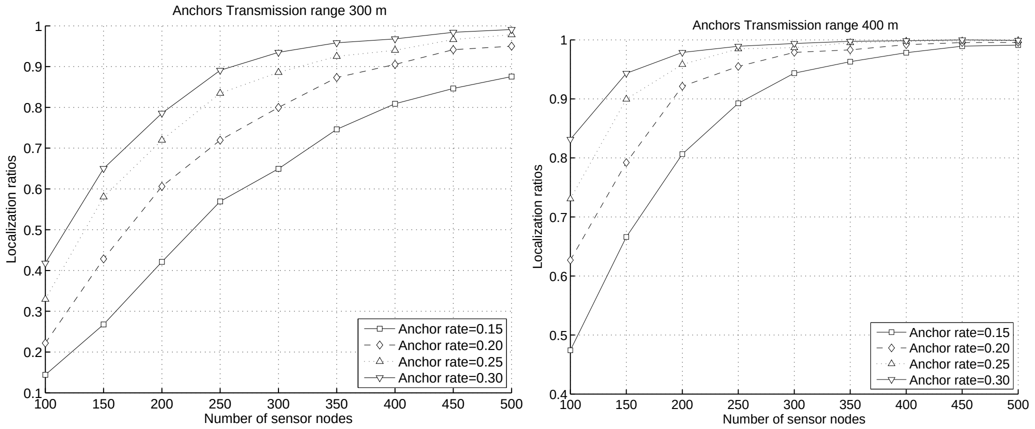

Figure 2. Localization ratio versus the number of sensor nodes

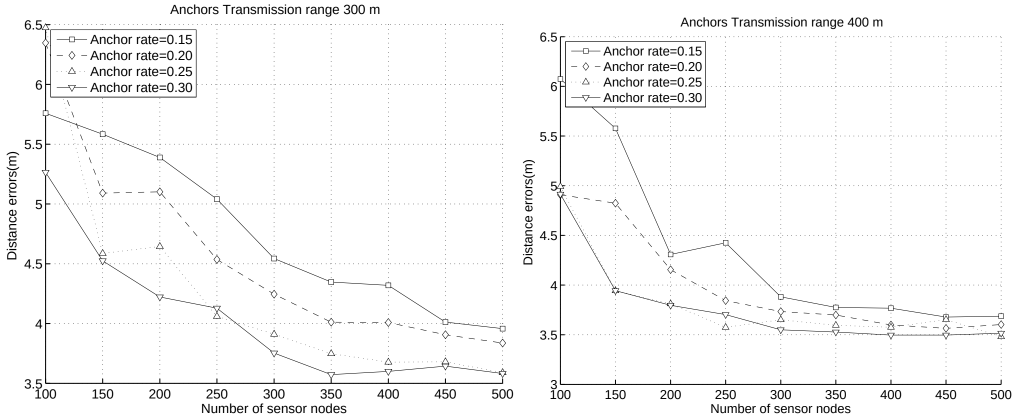

Figure 3. Distance errors versus the number of sensor nodes

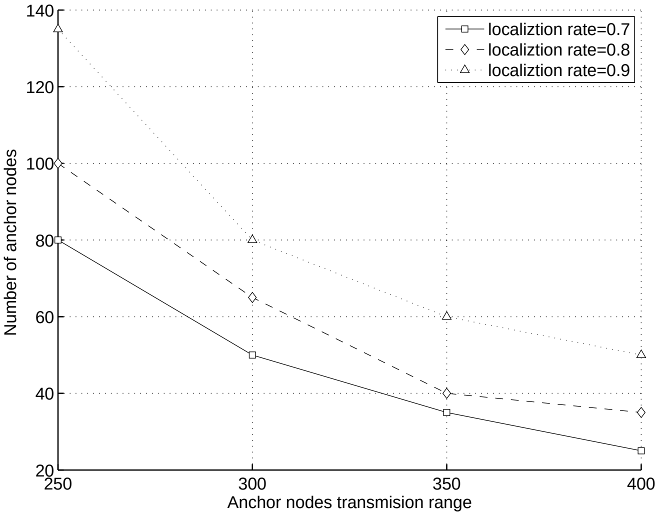

Figure 4. How the number of anchor nodes and the transmission range influence localization ratio.

3.2. Simulation results and analysis

In this paper we considered two performance metrics in our simulations: the localization ratio of located ordinary sensor nodes to the total nodes and the needed number of anchor nodes for good performance. The localization ratio is defined as the number sensor nodes that can be localized (with at least 3 broadcast messages from different anchor nodes). The localization ratio is considered at the different scenarios, with the number of sensor nodes varying from 100 to 500, the percent of anchor nodes varying from 15% to 30%, and the transmission range of anchor nodes varying from 250m to 400m. We also considerate the needed number of anchor nodes for different localization ratio at different anchor node transmission range.

We compare the localization ratio at different anchor node transmission range and anchor node ratio. The localization ratio performance is shown in Fig.2 for the communication ranges of 300m, 400m respectively. It can be observed that the communication range has a big impact on the localization ratio. With a transmission range of 400m, it is easy to achieve a more than 90% localization ratio. Note that only one hop broadcast message is used in the localization in our simulation, it is expected that the localization ratio can be significantly improved if multi-hop broadcast messages are to be used, which is left for our future work. It is also observed when the number of anchor nodes is less than 70, the localization ratio can be improved very quickly with the increase of the transmission range.

The corresponding average localization error performances are presented in Fig.3 for the communication ranges of 300m and 400m, respectively. It can be observed that the average localization error are quite small and is acceptable. With increased communications range, the average localization error decreases. The increased number of anchor nodes will also help reduce the average localization error. But if we compare to the localization ratio and localization error performances, we can find that the impact of communications range and number of anchor nodes on localization error is much smaller than that on localization ratio. Therefore, multi-hop based localization approach should be used to solve the localization ratio problem, which will be our future work.

To help on the network planning, we also studied the number of anchor nodes required to achieve a certain localization ratio. Typical results on the number of required anchor nodes versus the anchor node communication range are presented in Fig.4. The expected localization ratio is configured to 0.7, 0.8 and 0.9, respectively. The number of required anchor nodes can achieve the expected localization ratio for all the investigated scenarios with 100 to 500 overall sensor nodes. It is observed that with 350m and 400m communication ranges, it is easy to achieve good ratio with less than 60 anchor nodes in 1km x 1km x 1km underwater area. Hence we can use only 3 buoys with DETs, 60 anchor nodes with 350m transmission range in 1km x 1km x 1km volume that can acquire the same localization ratio as the DNRs scheme [11]. Compared to 25 buoys with GPS and similar DETs, our proposed scheme has much lower cost.

4. Conclusion

In this paper we proposed a new DET based hierarchical localization scheme. The new scheme inherits the merits of DNR scheme, such as simplicity and high localization ratio, but can significantly decrease cost of the system, and increase scalability and localization performances thanks to the hierarchical design. The new scheme mainly consists of four types of nodes: surface buoys, Detachable Elevator Transceivers (DETs), anchor nodes and ordinary nodes. Surface buoy is assumed to be equipped with GPS on the water surface. A DET is attached to a surface buoy and can rise and down to broadcast its position. The anchor nodes can compute their positions based on the position information from the DETs and the measurements of distance to the DETs. The hierarchical localization approach is scalable, and can be used to make balances on the cost and localization accuracy. Simulation results show that our proposed scheme has successfully achieved the design goals and outperform the existing schemes. In our future work, we will test the proposed scheme under more network scenarios and present more results.

Acknowledgment

The work is supported by the National Grand Fundamental Research 973 Program of China under Grant No.2006CB303007 and No.2007CB316506.

References

[1] I.F. Akyildiz, “State of the art in protocol research for underwater acoustic sensor networks,” Proceedings of the 1st ACM international workshop on Underwater networks, 2006.
[2] J. Kong, J. Cui, et al, “Building underwater ad-hoc networks and sensor networks for large scale real-time aquatic applications,” IEEE MILCOM, 2005.
[3] I.Akyildiz, et al, “Underwater acoustic sensor networks: research challenges,” Ad Hoc Networks Journal,
[4] V. Chandrasekhar,et al, “Localization in underwater sensor networks: survey and challenges,” WUWNet, pp.33-40, 2006.
[5] J. Heidemann, et al, “Research challenges and applications for underwater sensor networking,” IEEE Wireless Communications and Networking Conference , 2006.
[6] J. Partan, J. Kurose, et al, ”A survey of practical issues in underwater networks,” WUWNet,
[7] Z. Zhou, J.-H. Cui, and S. Zhou, “Localization for large-scale underwater sensor networks,” in UCONN CSE Technical Report:UbiNet-TR06-04, 2004.
[8] V. Chandrasekhar and W. K. G. Seah, “Area localization scheme for underwater sensor networks,” Proceedings of the IEEE OCEANS Asia Pacific Conference, 2006.
[9] L. Doherty, K. S. J. Pister, et al, “Convex position estimation in wireless sensor networks,” Proceedings of IEEE Infocom,Mar. 2001.

[10] C. Bechaz and H. Thomas, “GIB system: The underwater GPS solution,” Proceedings of 5th Europe Conference on Underwater
Acoustics, May 2000.
[11] M. Erol, L. Vieira, et al, “Localization with Dive’N’Rise (DNR) beacons for underwater acoustic sensor networks,” Proceedings of ACM International Workshop on Underwater Networks , Sep 2007.
[12] D. Niculescu, B. Nath, “Ad-hoc positioning system,” in proc: IEEE Globecom, 2001.
[13] C. Savarese, K. Langendoen, J. Rabaey, “Robust positioning algorithms for distributed ad-hoc wireless sensor networks,” in USENIX Technical Annual Conference, CA, pp. 317-328, 2002.
[14] A. Savvides, H. Park, M. Srivastava, “The bits and flops of the N-hop multilateration primitive for node localization problems,” in proc: First ACM International Workshop on Wireless Sensor Networks and Applications (WSNA), Atlanta, GA, pp. 112-121, 2002.
[15] K. Langendoen, N. Reijers, “Distributed localization in wireless sensor networks: a quantitative comparison,” Computer Networks, vol.43, pp. 499-518, 2003.