A Multiple Anchor Nodes Cooperative Localization Method for Underwater Wireless Sensor Networks

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Abstract
The underwater sensor node location depends on the position coordinate information provided by the anchor nodes. Generally, there are far less anchor nodes than ordinary nodes deployed in the underwater network because of their higher cost. Since the anchor nodes are randomly deployed in the underwater network, the nodes’ keep moving and dispersing due to water flow will lead the emergence of isolated nodes. The isolated node can’t be located if it can’t obtain enough neighbor anchor node’s location information. In view of this problem, this paper presents a multiple anchor nodes cooperative localization method MACL to estimate two-hop anchor nodes’ distance. In MACL, the unknown nodes will request two-hop anchor nodes’ information from their neighbor nodes when the number of one-hop anchor nodes is insufficient. The unknown node will select two neighbor nodes with a common one-hop anchor node. Then the unknown node constructs the geometry including the unknown node, estimate the distance between unknown nodes and the anchor node of the two neighbor nodes by looking for the geometric shapes edge – angle relationship between them. Thus, the position of the unknown nodes is calculated by using the trilateral measurement method through projection technique. This paper uses MATLAB simulation platform to simulate the proposed MACL location method and compared with the existing location method. The experimental results show that the proposed method has higher node coverage and smaller localization error.

Key words: Underwater Wireless Sensor Networks (UWSNs); Node Localization Algorithm; 3D; Geometric Shapes; Edge – Angle.

1. INTRODUCTION
More than 70% of the Earth's area is covered by oceans, lakes, rivers and other waters. The vast ocean space and the abundant marine resources have played a very important role in promoting national economic growth. Therefore, all countries attach great importance to the application and research work of Underwater Wireless Sensor Networks (UWSNs).

Underwater sensor networks consist of a variable number of relatively low-cost, self–organizing, and mobile sensor nodes to monitor oceanic environment collaboratively (Akyildiz,2002; Pompili,2006). Between the nodes take the water channel as a communication channel, through the way of water communication to communicate with each other. Sensor nodes deployed in monitoring area collect data and send it to a base station via communication link for further processing. Sensed data is meaningless without location information (Heidemann,2006). Underwater sensor network nodes are suitable for large-scale deployments and are powerful enough to accomplish specific tasks through match different functional sensor nodes. One of the most important functions of an underwater sensor network is to locate the sensor nodes or to locate the monitoring targets. It is the basic technical support for applications, which is the most basic and necessary information for the underwater sensor network in the practical application environment (Mirza, 2013). In many underwater applications, such as environmental monitoring, disaster prevention, target tracking should be tagged with location information (Freitag and Stojanovic,2002). Location information can also support underwater topology control, MAC protocol, and routing protocol; for example, location-based routing protocol needs to be supported by underwater localization technology.

Radio waves get heavily attenuated when traveling through water. In condition of that, global positioning system (GPS) cannot be used for localization of underwater sensor nodes (Cui and Kong,2005). Instead, acoustic signals are commonly used for underwater communication. The characteristics of acoustic signals are different from radio signals. The speed of acoustic travels at approximately 1500 m/s which is five orders of
magnitude lower than radio wave. The speed is variable as the temperature, pressure, and salinity of water changes. Therefore, the characteristics of acoustic signals raise some problems such as high propagation, low bandwidth and high bit error rate, which makes underwater localization more challenging (Cui and Kong, 2006). From now on, researchers have proposed many localization methods for terrestrial wireless sensor networks. However, due to the unique characteristic of underwater environment, most of these methods are not appropriate to UWSNs.

Generally, the localization methods for terrestrial wireless sensor networks need the assistant of anchor nodes whose position can be obtained in advance by GPS or other direct positioning method. The underwater sensor network is deployed in a three-dimensional space where localizing one node needs at least four known anchor nodes. After projecting the reference node to the plain of unknown node, locating a node requires only three reference nodes. This requires the sensor node to be equipped with a pressure sensor capable of measuring its own depth information (Chandrasekhar and Seah, 2009).

In the process of positioning, the proportion of the placement of anchor nodes profoundly affects the positioning coverage and positioning accuracy of the whole network. Since the cost of anchor nodes is higher than that of ordinary nodes. To a certain extent, the more anchor nodes deployed, the higher the proportion, the more conducive to improve the positioning of the coverage and reduce the positioning error, but at the same time, the cost for deploying the entire network will increase. Anchor node deployment ratio is low, although the cost saves, but there will be a lot of unbound nodes because they cannot get a sufficient number of anchor node information. And it is difficult to deploy anchor nodes at precise location in underwater environments. In most cases the anchor nodes are randomly deployed, the deployment has a certain degree of non-uniformity. At the same time, due to the movement of nodes caused by the touch of aquatic organisms and the movement of water and, these will cause the number of unknown nodes’ one-hop anchor nodes is insufficient and lead the unknown nodes cannot be located, thus affecting the function and significance of deploying the underwater sensor network.

There are two kinds of methods for solving this problem. The first one is called AUV-aided algorithm (Erol, 2007; Liu and Liu, 2013), in which AUV travels to an area where the unknown nodes obtain insufficient anchor nodes and then serves as a localization reference. However, the method is not able to provide real-time localization, especially in large scale UWSNs, because the number of AUVs is scare and they move slowly; the other is multi-hop localization algorithm. The proposed MACL in this paper is based on the depth information, when anchor nodes’ deployment rate is low and the unknown node cannot obtain enough number of hop anchor node information, will send the request help information to neighbour nodes. The neighbour node needs to help the unknown nodes to find two-hop anchor nodes and to estimate the distance between the unknown node and the two-hop anchor node, when number of the unknown node’s anchor node meets three and more than three then the anchor nodes can be projected through the projection. Then the unknown node can be localized.

The rest of this paper is organized as follows. Section 2 provides a brief overview of related work. In section 3 we propose a multiple anchor nodes cooperative localization method for Underwater Sensor Networks. In section 4 the proposed algorithm is validated by simulations in terms of localization coverage and localization error. Section 5 is the conclusion.

2. RELATED WORK

Typical localization techniques can be broadly classified into two categories: range-based algorithm and range-free algorithm. Range-based schemes first measure or estimate distance or angle between unknown nodes and anchor nodes by using Time of Arrival (TOA) (Go and Chong, 2015), Time Difference of Arrival (TDOA) (Miyazaki, 2015), Angle of Arrival (AOA) (Jiang, 2012; Stefano, 2008), or Received Signal Strength Indicator (RSSI) (Tran-Xuan, 2009). The algorithm will then transform ranges into nodes’ position information applying triangulation or multilaterate. Range-free algorithm do not use range measurement to estimate distance between nodes. In these algorithms, nodes are located through the network topology or the positioning of surrounding anchor nodes (Zhou, 2009), which can be generally classified into hop count-based and area-based algorithm. Range-based algorithm generally can achieve higher location accuracy than range-free schemes. In order to take the advantage of the slow propagation speed of sound in water to achieve better accuracy, range-based algorithms are preferred for UWSNs. In this paper, we prefer using range-based algorithm. In this section, we briefly review those localization techniques for UWSNs that are similar to discussed herein.

In (Chandrasekhar, 2006), the researchers present an area-based range-free underwater positioning (area localization scheme, ALS). ALS relies on the variable power lever of anchor nodes to partition the plan into areas. Each anchor node has its own partition. A sensor receives its position estimate from a central server after providing all the areas where it resides.

LDB was proposed in (Luo, 2010), it uses AUV to broadcast its own coordinates when the AUV sail a distance. AUV signal transmission angle is 60 degrees, so the signal coverage area is a sector area. AUV will surface after sailing underwater for some time, through the GPS signal to re-correct their own coordinates, In the
AUv dive process through the pressure sensor to calculate their own depth information. The node records the coordinates of the first received AUv broadcast message and the last received AUv broadcast coordinates. And the unknown nodes use these messages to locate their own position. LDB works well with sparse underwater sensor networks, but the positioning accuracy and the average error depend on the AUv signal transmission frequency and the localization propagation is long because the AUv moves slowly. LoMoB is proposed in (Lee,2012), it based on the localization scheme LDB. The difference is the author also put forward the concept of residual, and the determine weights based on residuals. Use the weights to average the weighting of the unknown nodes’ candidate positions as the position of the unknown nodes.

DNR was proposed in (Erol,2007), with beacons sinking and rising in the water, the nodes can be localized by passively listening to those beacons. DNR assumes that nodes are synchronized which increases the communication cost. SLMP was proposed for large scale underwater sensor networks (Zhou and Cui,2011). The SLMP employs GPS-enabled surface buoys and special-purpose anchor nodes. The anchor nodes are deployed subsurface among other less powerful underwater sensors, but have the ability to self-localize via direct communicate with four surface buoys. By utilizing the predictable mobility patterns of underwater sensor nodes, SLMP can balance the tradeoff between localization accuracy, localization coverage and communication costs. Though high radio of anchor nodes improves the accuracy of localization, it is achieved at a higher cost, for the anchor nodes may be more expensive and deploying anchor nodes is more difficult.

LSL was proposed in (Zhou and Cui,2010), in LSL the unknown nodes receive the broadcast information of the anchor node estimates the distance by TOA or other ranging techniques. When the ordinary node measured distance to at least four different anchor nodes can be distributed perform the positioning process. When the number of ordinary nodes’ anchor nodes is less than four, ordinary nodes need to measure the distance between two jump anchor nodes by three-dimensional Euclidean method. The normal node that has been successfully positioned will be selected as the reference node to assist in the positioning of the remaining common nodes. This method needs more communication between nodes while having high computational complexity.

MFILA was proposed in (Liu,2015), in the localization scheme each node has a rotatable acoustic transmitter and receiver. Acoustic transmitter and receiver on nodes can rotate anticlockwise in horizontal direction. MFILA will be executed when unknown nodes cannot find 3 neighbouring beacons. Some intermediate nodes are employed to form a polygonal line from the unknown nodes to the nearest beacons. Subsequently, this polygonal line is fitted for trilateration localization. This solution requires that each node be equipped with additional hardware, this causing the cost of the network is too much.

Vijay K and Neeraj Jain (Chaurasiya,2014) have proposed a novel distance estimation approach for 3D localization in wireless sensor network using multi-dimensional scaling. The localization algorithm is divided into three steps. First, the algorithm estimates distances between all pairs of nodes in the WSN. Second, the algorithm estimates local coordinate of nodes in the networks using MDS. Third, the local coordinates of nodes will be transformed into a global coordinate system. The scheme needs to measure the distance between all node pairs in the network, which is not realistic. In addition, the distance measurement error between nodes will be relatively large. In (Beniwal,2016), the authors propose a localization scheme for underwater sensor networks, the scheme uses some mobile nodes to help localization which are called mobile beacons. These mobile nodes can dive and rise in the sea with the help of extra weight and after going to the deepest point of deployment, they rise again to come at the sea surface. Mobile beacons have GPS module to receive their coordinates when floating on the sea surface. And they use acoustic transceiver to broadcast localization message when diving into the water at fixed beacon interval. Sensor nodes are assumed to be static in the underwater network. Sensor nodes measure distances from three mobile beacons to figure out its own position. This scheme can achieve localization without time synchronization. But it assumes the mobile beacons to float and dive vertically, which is difficult to be guaranteed in the actual situation. The number of mobile beacons and the location of the deployment have a significant impact on the positioning results.

If there is no direct communication between anchor nodes and ordinary nodes, the network connectivity can be explored for range estimation such DV-hop (Gui,2015; Xu,2015), DV-distance (Shi,2013), and Euclidean. Different from the methods mentioned above, our proposed method MACL is a high localization coverage scheme for underwater sensor networks. When the number of unknown nodes’ one-hop anchor nodes is insufficient for localization, we will use a new method to estimate the distance between two-hop anchor nodes and unknown nodes. When the number of anchor nodes is sufficient, the unknown node will project the anchor nodes to its depth, both anchor nodes and unknown nodes have pressure sensor to measure their depth, and then calculate its coordinate through trilateration. If an unknown node locate itself successfully and then it will serve as a reference node to help other nodes need to be localize.

3. PROBLEM STATEMENT

More than 70% of the Earth's area is covered by oceans, lakes, rivers and other waters. The vast ocean
space and the abundant marine resources have played a very important role in promoting national economic growth. Therefore, all countries attach great importance to the application and research work of Underwater Wireless Sensor Networks (UWSNs).

3.1. Structure

Figure 1 is a UWSN environment. There are two types of nodes in the network: anchor nodes and ordinary nodes. The anchor node knows its location in advance. The common node estimates the position by communicating with the anchor node.

Anchor nodes and unknown nodes are evenly distributed in the underwater environment. Due to the cost of the sensor network, the amount of anchor nodes is much less than the number of ordinary nodes. It is a matter of great consideration and research to achieve high positioning coverage and small positioning errors in the case of lower-proportion anchor nodes deploying, uneven deployment and various factors that lead to node movement due to various factors in the water environment. In this paper, the underwater sensor unknown node knows its depth information through the pressure sensor. The network model used in this paper does not require very special nodes such as ups and downs and AUV.

![Figure 1. A typical underwater sensor network setting](image)

This section provides an overview of the MACL positioning process. The whole positioning process will be divided into node projection position calculation and two-hop anchor node distance estimation. Figure 2 shows the MACL positioning process block diagram.

![Figure 2. MACL positioning process block diagram](image)

After the positioning is initialized, the anchor node broadcasts information to the whole network, including the ID, coordinates and transmission time information of the anchor node. After the node receives the broadcast information of the anchor node, and then establish a local storage list to store their own neighbor anchor nodes, also set a counter m to record the amount of its own neighbor anchor nodes.

The distance between the unknown node and its neighbor anchor nodes can be measured by TOA technology.

After the anchor node broadcasts the positioning information, the amount of neighbor anchor nodes of the unknown node will appear two cases: equal or greater than three and less than three. Since the pressure sensor can acquire the depth information, all unknown nodes can be positioned after satisfying three distance information with the anchor nodes.
When the amount of neighbor anchor nodes is equal or greater than three, the unknown node can be calculated by projection calculation process.

When the amount of neighbor anchor nodes is less than three, the unknown node does not have enough number of anchor nodes to assist in its positioning. The node cannot be located by the traditional trilateration technology. The two-hop anchor node distance measurement takes full account of the occurrence of such a situation can let the unknown node to find more anchor nodes information to complete the positioning. The unknown node needs to send request assistance information to its neighboring neighbor nodes to find the information of the two-hop anchor nodes, and then its neighbor node will feedback its own anchor node information. The unknown node chooses the two neighbor nodes containing the same one-hop anchor node to construct the geometric relation to obtain the two-hop anchor node location and distance information. When it gets enough anchor node information, it can calculate its own position. Through the two-hop anchor node information will effectively improve the localization coverage of the nodes.

3.2. Projection Localization Calculation

This paper uses the projection positioning mechanism. The depth information of the node is obtained by the pressure sensor of the node. So, the unknown node can get the positioning operation when it gets three anchor nodes information.

As shown in Figure 3, node 1 is the unknown node to be located. Suppose its coordinate is, is the depth information measured by the pressure sensor. Node 2, node 3, node 4 are anchor node, their coordinates information is known. Their coordinates are \((X_1, Y_1, Z_1)\), \((X_2, Y_2, Z_2)\), \((X_3, Y_3, Z_3)\).

![Figure 3. Projection positioning diagram](image)

\(l_1\) is the distance between node 1 and anchor node 2, \(l_2\) is the distance between node 1 and anchor node 3, \(l_3\) is the distance between node 1 and anchor node 4. They are obtained by TOA ranging technique. Node 5 is the projection node where node 2 is projected onto the depth plane of node 1. Node 6 is the projection node where node 3 is projected onto the depth plane of node 1. Node 7 is the projection node where node 4 is projected onto the depth plane of node 1.

\(d_1, d_2, d_3\) respectively, calculated by the formula (1), (2), (3).

\[
d_1 = \sqrt{l_1^2 - (Z - Z_1)^2}
\]

\[
d_2 = \sqrt{l_2^2 - (Z - Z_2)^2}
\]

\[
d_3 = \sqrt{l_3^2 - (Z - Z_3)^2}
\]
The equations (3-4) can then be listed to solve the coordinates of the unknown nodes.

\[
\begin{align*}
(x - X_1)^2 + (y - Y_1)^2 &= d_1^2 \\
(x - X_2)^2 + (y - Y_2)^2 &= d_2^2 \\
(x - X_3)^2 + (y - Y_3)^2 &= d_3^2
\end{align*}
\]

(4)

It is important to note that the projected nodes cannot be collinear when the selected three anchor nodes are projected onto the plane where the unknown node is located. Assume that the coordinates of the three anchor nodes are \((x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3)\) respectively. Determine whether the projection nodes of the three anchor nodes are collinear only need to determine whether the formula (3-5) is true. If the formula (3-5) is not established, the projection nodes of the three anchor nodes are not collinear, otherwise the three nodes after projection are collinear.

\[
\begin{pmatrix} x_3 - x_1 & y_3 - y_1 \\ x_1 - x_2 & y_1 - y_2 \end{pmatrix} = 0
\]

(5)

3.3. Two-hop anchor nodes distance estimation

In order to solve the problem that the unknown node cannot be accurately positioned when the anchor node around the unknown node in the positioning process is insufficient. MACL uses the neighbor node to construct the geometry of the unknown node to the two-hop anchor nodes. The geometric angle transformation is used to find the distance between the unknown node and the two-hop anchor.

As shown in Figure 4, node A is an unknown node, node B and node C is neighbor nodes of unknown node A. Node D is the anchor node and node D is both the neighbor anchor node of node B node C. But the node D is not within the communication range of the unknown node A. Therefore, during the initialization process, the ordinary node does not receive enough anchor node information after the anchor node has broadcast the location information, so it needs to calculate the distance to the multi-hop anchor node D.

After the anchor node broadcasts, node A does not receive enough number of anchor node information. Node A will send request assistance information to its neighbor node with insufficient number of anchor nodes to find two-hop anchor node information. Its neighbor node will send its one-hop anchor node information to node A after receiving the request information of node A. The information includes the depth of node B, node C, and the neighboring nodes as node A, and the coordinates of the neighbor anchor node of the neighbor node which is the coordinate information of the neighbor anchor node D, and the distance information between them. In Fig 4, node A can know the distance to neighbor nodes B and C at this time which \(l_{ab}, l_{ac}\) are known. The depth information of node B and node C can be known by pressure sensor. Because node D is both the neighbor anchor node of node B and node C. After nodes B and C transmit the neighbor anchor nodes to node A, node A can know the distance from node B to node D and the distance from node C to node D which \(l_{bd}, l_{cd}\) are known.

![Figure 4. Two-hop anchor node distance estimation](image)

At this point node A can make B, C, D project to the plane of the node A through projection technology to build a geometric figure to calculate the distance between node A and node D. The points B’, C’, D’ are the projection nodes of B, C, D project to the plane of the node A respectively.
Since the depth information of nodes A, B, C, and D is measured by the pressure sensor of the node itself, the vertical distance can be calculated by the difference in depth after nodes B, C, D projecting to the plane of node A. That is, the distance between B and B' \( l_{BB'} \), the distance between D and D' \( l_{DD'} \), and the distance between C and C' \( l_{CC'} \) can be calculated.

In the quadrangle BB'D'D, because the DD' perpendicular to the surface AB'D'C', according to the nature of the straight line and the perpendicular to the plane: a straight line perpendicular to a plane, the line perpendicular to the plane of the general line. So, DD' is perpendicular to B'D'. The vertical line of the node B is given to the node E, as shown in Figure 5.

![Diagram of quadrilateral BB'D'D](image)

**Figure 5.** Quadrilateral BB'D'D 'schematic

The distance between E and D' is equal to the distance between B and B'. The distance between D and E is:

\[
l_{DE} = l_{DD'} - l_{DE}
\]

(6)

The triangle BED is a right-angled triangle, where the oblique edge BD and a right-angled edge DE know that the distance of the other right-angled edge BE is obtained from the Pythagorean Theorem:

\[
l_{BE} = \sqrt{l_{BD}^2 - l_{DE}^2}
\]

(7)

\[
l_{AE} = \sqrt{l_{AD}^2 - l_{AE}^2}
\]

(8)

Similarly, in the triangle ACC', the distance between A and C' is:

\[
l_{AC} = \sqrt{l_{AC}^2 - l_{CC'}^2}
\]

(9)

At this time in the plane AC'D'B', the distance A and C', A and B', B' and D', B' and C', C' and D', \( l_{BC}, l_{AB}, l_{B'C'}, l_{B'C}, l_{C'D}, l_{C'D} \) can be calculated. In the triangle AB'C' in the trilateral distance is known, so \( \angle ABC' \) can be obtained:

\[
\cos(\angle ABC') = \frac{l_{BB'}^2 + l_{BC'}^2 - l_{AC}^2}{2 \cdot l_{BB'} \cdot l_{BC'}}
\]

(10)

\[
\angle ABC' = \arccos\left(\frac{l_{BB'}^2 + l_{BC'}^2 - l_{AC}^2}{2 \cdot l_{BB'} \cdot l_{BC'}}\right)
\]

(11)

In the triangle CB'D', the three sides of the distance are also known, it can also be obtained:
\[
\cos(\angle C'B'D') = \left( \frac{l_{B'C}^2 + l_{B'D}^2 - l_{C'D}^2}{2 \cdot l_{B'C} \cdot l_{B'D}} \right)
\]
(12)

\[
\angle C'B'D' = \arccos\left( \frac{l_{B'C}^2 + l_{B'D}^2 - l_{C'D}^2}{2 \cdot l_{B'C} \cdot l_{B'D}} \right)
\]
(13)

In the triangle \( AB'D' \), the formula (11) and the formula (13) are added:

\[
\angle AB'D' = \angle AB'C' + \angle C'B'D'
\]
(14)

Therefore, the distance between \( A \) and \( D' \) can be obtained from the distance of the formula (14) and \( A \) and \( B', B' \) and \( D' \).

\[
l_{AD} = \sqrt{l_{AB'}^2 + l_{B'D}^2 - 2 \cdot l_{AB'} \cdot l_{B'D} \cdot \cos(\angle AB'D')} \]
(15)

The distance between the node \( A \) and the node \( D \) can be calculated from the Pythagorean theorem by the formula (15) and the length of \( D \) and \( D' \) in the right angle triangle \( AD'D' \):

\[
l_{AD} = \sqrt{l_{AD'}^2 + l_{D'D}^2} \]
(16)

For the case of Figure 4, node \( A \) may also appear at point \( A' \) after the projection of node \( B, C, \) and anchor node \( D \) on the other side of \( B'C' \), see Figure 6.

According to the distance process of solving \( A \) and \( D \), the distance between \( B' \) and \( A' \) can be obtained in triangular \( B'AB \). The distance between \( A \) and \( C \) can be solved in the triangle \( A'C'C \), and the distance between \( B \) and \( D' \) can be obtained in the quadrangle \( B'D'DB \). The distance between \( B \) and \( C' \) can be obtained in quadrilateral \( B'C'CB \). Therefore, in the triangle \( A'B'C' \), can be obtained through the three sides known. Also in the triangle \( DB'C \) three sides are also known and can be obtained. So, can be obtained by subtracting. At this time, in the triangle \( A'B'D' \), both sides \( B'A', B'D' \) and their angle have been obtained. Using the cosine theorem, we can find the length of the three sides \( A' \) and \( D' \). The triangle \( A'D'D \) is a right-angled triangle, and its two right-angled edges are known, so the distance of \( A'D \) can be determined by Pythagorean Theorem.

4. SIMULATION

In the simulation experiment, 500 nodes were randomly deployed in the 100m * 100m * 100m area. Assuming that the range measurement between nodes follows a normal distribution, the actual distance is the average, and the standard is 1% of the actual distance. This is a reasonable assumption that it is easy to
implement in existing underwater sensor nodes. We change the node's density by changing the communication distance of the node. The radius of the communication is set to vary from 17 m to 21 m in step size, which results in an average node density varying from 8 to 16, taking into account 5%, 10% and 20% of the anchor nodes. The experimental results were compared with the methods and methods of LSL in the literature (Zhou, 2010; Zhe, 2015).

Figure 7 shows that MACL outperforms both LSL and algorithm in (Zhe, 2015). As the density of the nodes increases, both MACL and LSL will have more neighbors. The node that was previously unable to locate is now more likely to find two-hop anchor nodes through the neighbors' nodes, and then can figure out the distance between them. This allows the unknown node to find more anchor nodes to locate the node. The Algorithm in (Zhe, 2015) is only able to locate by the one-hop anchor node. So, it has the lowest coverage and the slowest growth.

![Figure 7. Localization coverage Anchor percentage=5%](image)

Figure 8 shows the status of the node location coverage when the anchor nodes ratio is 10%. Obviously, both MACL and LSL are better than those in the literature (Zhe, 2015). But our approach can achieve higher location coverage. On the one hand, it shows that it can improve the coverage ratio by looking for two-hop anchor nodes, on the other hand, our solution uses fewer neighbors when we are looking for two-anchor anchors. So, it's very limited to be localized to only rely on one-hop anchor node. Its location coverage is heavily dependent on anchor node deployment. MACL can handle such limitations well, reducing the reliance on the initial proportion of anchor nodes to improve the network's location coverage.

![Figure 8. Localization coverage Anchor percentage=10%](image)

Figure 9 shows even when the node density is 8, the MACL and LSL node location coverage has reached a higher level, and the method in the literature (Zhe, 2015) has obviously improved. So, it can be seen the amount of anchor nodes is important for location coverage. But given the cost factors, the amount of anchor nodes cannot increase indefinitely. The location coverage of MACL positioning method is still higher than the LSL method and Algorithm in (Zhe, 2015).
The overall comparison of the MACL with the other two methods in terms of the ratio of the anchor nodes to 5%, 10%, and 20%, MACL has a better adaptability in the lower portion of the anchor node, can achieve higher localization coverage.

Figure 10 shows the accuracy of the three methods. When the ratio of anchor nodes is 5%. And we can see from the diagram that when the node density is small, MACL's localization accuracy is similar to that of LSL. As the density of the nodes increases the localization accuracy of MACL decreases and is less than the LSL localization method. This is because MACL's localization coverage is much faster than LSL as node density increases, MACL can locate more nodes than LSL, the accumulation of node error is relatively larger, and resulting in the localization accuracy is relatively larger. But the reduction in location accuracy is much slower than the growth rate of location coverage. There is a slight reduction in positioning accuracy, but the location of the nodes has increased significantly. So, the sacrifice of this point is very significant.

Figure 11 shows that with the increase of anchor nodes, the localization accuracy of MACL is better than LSL, but Algorithm in (Zhe,2015) is the best. This is because under the same node density, when the unknown node has three one-hop anchor nodes information, MACL can use these three direct one-hop anchors to locate the unknown node, LSL also needs to find a two-jump anchor node to locate. And the distance measurement error of the two-hop anchor nodes is obviously greater than the distance error of one-hop anchor node. And The method locates an unknown node (Zhe,2015) using only one hop anchor node. However, the gap between MACL and the Algorithm in (Zhe,2015) is not very large in localization accuracy, and considering the high localization coverage of MACL, the advantages of MACL can be clearly demonstrated.
Figure 11. Localization accuracy Anchor percentage=10%

Figure 12 shows that MACL and the other two methods do not change significantly as the node density increases, and they also have similar positioning accuracy. This is because the number of anchor nodes in the network is relatively large, most nodes of the neighbor anchor nodes can meet the positioning requirements, only a few nodes need to measure the distance between the two anchor nodes. When the anchor ratio is 5%, 10% and 20%, the position accuracy of the unknown node depends on the proportion of the anchor nodes. In particular, the anchor nodes are sparse deployment, the increase in the number of anchor nodes to improve the positioning accuracy is very helpful. However, when the amount of anchor nodes reaches a certain point, by increasing the number of anchor nodes, the impact on the position accuracy is weak. At a lower proportion of anchor nodes, MACL has better positioning accuracy than LSL. When the proportion of anchor nodes is high, MACL positioning accuracy and the other two methods are very close.

Figure 12. Localization accuracy Anchor percentage=20%

5. CONCLUSIONS

In this paper, we propose a positioning method to achieve UWN high positioning coverage and high positioning accuracy. In this method, the whole localization process consists of three sub-processes: projection localization calculation, two-hop anchor nodes distance estimation and iterative localization. The unknown can be located with three anchor nodes information by projection techniques in 3d environment. This reduces the complexity of computing and reduces the burden of nodes. During the two-hop anchor node distance estimation process, the unknown node can find the two-hop anchor nodes and measure the distance between them. This can compensate for the lack of reference nodes of unknown nodes and improve the location coverage of the network. In order to take full advantage of the location node to provide location services, the next step to perform iterative locator process. The method achieves the expected effect.

Future work: (1) the localization method proposed in this article is to simulate and experiment in MATLAB, and then will deploy the sensor network in the actual water environment, and analysis node location coverage, location accuracy. (2) On the basis of this approach, further research and improvement of the information acquisition and distance measurement of anchor nodes can be carried out.

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