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Distributed Localization Based on Signal Propagation Loss for Underwater Sensor Networks

GANG QIAO, (Member, IEEE), CHEN ZHAO, FENG ZHOU, (Member, IEEE), AND NIAZ AHMED, (Member, IEEE)
Acoustic Science and Technology Laboratory, Harbin Engineering University, Harbin 150001, China
Key Laboratory of Marine Information Acquisition and Security, Ministry of Industry and Information Technology, Harbin Engineering University, Harbin 150001, China
College of Underwater Acoustic Engineering, Harbin Engineering University, Harbin 150001, China

Corresponding author: Feng Zhou (zhoufeng@hrbeu.deu.cn)

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ABSTRACT Localization technology for Underwater Wireless Sensor Networks (UWSNs) plays an important role in detection and navigation for underwater vehicles. In this paper, we therefore propose a novel localization scheme for UWSNs based on the propagation loss, named Communication Signal Propagation Loss Localization Scheme (CSPLLS). CSPLLS is a cooperative, passive, asynchronously distributed localization method where the target only uses communication signal's strength from anchor nodes. The method is appropriate for a long-distance and large-scale positioning in shallow sea. Main innovative point of the research is to locate with a new rang-based method using signal propagation loss. Experiment and simulation results are presented in the paper which confirms that the proposed scheme provides a relatively high precision of as low as 2.2% positioning error with centroid optimization. Major advantages of this method includes: 1) getting rid of clock resources usually used in each node for localization, 2) reducing the total localization time, 3) saving the energy of each node which prolongs the lifetime of networks and 4) realize the design of underwater communication and localization integration.

INDEX TERMS Underwater localization, underwater wireless sensor networks, sound propagation loss, distributed localization.

I. INTRODUCTION

Underwater positioning or localization plays an important role in underwater wireless sensor networks (UWSN) [1]. With the advancement of technology, underwater exploration and development, UWSNs are growing bigger and bigger [2]. Recently, autonomous underwater vehicles (AUVs) and unmanned underwater vehicles (UUVs) are playing important role in underwater exploration and monitoring [3], [4]. With such growing applications, it becomes really important to have efficient, accurate and low power localization schemes [5], [6]. A poor localization scheme can highly risk underwater wireless sensor networks performance and may lead to failure of the target goals.

Underwater positioning technology is extremely important for ocean development and exploration [7]. Since UWSNs may have large number of nodes, accurate localization can significantly help to reduce hardware cost [8]. Generally, the UWSNs consist of three kind of nodes: anchor nodes, unknown nodes and reference nodes [9]. The aim of underwater positioning is to use algorithm to get the target location based on limited available communication information from anchor nodes and reference nodes [10].

There are many localization algorithms for terrestrial wireless sensor networks (TWSNs) such as time of arrival (TOA) and time difference of arrival (TDOA) that use hardware to measure the distance information. These kinds of methods have higher accuracy, but at the same time they increase the network cost and energy consumption [11]. Received signal strength indicator (RSSI) helps to reduce the power

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consumption but also compromise the positioning accuracy [12]. Research is therefore being done to minimize this trade-off.

On the other hand, localization in UWSNs is not as mature and is still challenging due to some major technical differences. Acoustic communication has a bigger propagation delay, lower bandwidth and higher error rate compared to the terrestrial communication [13]. The algorithms based on transmission of large amount of data or real-time communication in TWSN thus will not be applicable for UWSN. As radio signal and acoustic signal have different propagation model so RSSI algorithm can also be not applied to underwater directly. Moreover, the batteries of underwater sensor nodes can rarely be replaced and the energy is strictly limited, so under normal circumstances, it is difficult to achieve higher localization accuracy and localization coverage rate in an underwater environment [14], [15].

To deal with the challenges in underwater positioning, various localization algorithms have been proposed for UWSNs. Positioning methods based on UWSNs can be divided into distributed localization and centralized localization [16]. In distributed localization algorithms, each unknown node collects localization information and then runs a location estimation algorithm individually. In centralized localization algorithms, the location of each unknown node is estimated by a base station or a sink node. Distributed localization method is suitable for large-scale and multiple target localization such as AUVs positioning, while centralized localization method is used for sensor arrays generally attached to a large underwater target [17].

Localization methods for UWSNs can also be divided into range-based and range-free methods [15], [18]. The range-based methods such as TDOA and TOA use clock resources to measure the distance information with speed of sound. These kinds of method can provide higher accuracy, but they increase the network cost and energy consumption. Besides, the clock synchronization and network protocols with each node, add more complexity to the system. The range-free methods use the connectivity of the network to locate the unknown nodes. The typical range-free methods mainly include the DV-HOP, Area Localization Scheme(ALS), Asymmetrical Round Trip based Localization(ARTL), Convex Programming and Centroid Localization algorithm. These methods does not require additional hardware and have lower energy consumption with shorter positioning time, but their accuracy is usually lower. We summarize the existing localization algorithm for UWSNs and show in Figure 1.

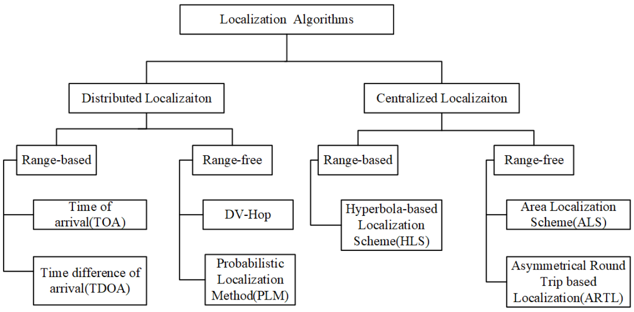


FIGURE 1. Localization algorithm classification in UWSNs.

The primary goal and focus of the underwater localization research is to improve the positioning accuracy and reduce the processing time and system power consumption. Many methods have been proposed to optimize the positioning process. A new approach for localizing underwater sensor nodes is presented by Bo *et.al.* [19] to locate AUVs, where each AUV broadcasts its position and the time while sending the messages. The nodes in the communication range can then receive the messages and detect the range differences from the four AUVs to the sensor nodes. The main objective of this method is to realize a fast localization for AUVs with UWSNs and improve the positioning accuracy to an extent [19].

In another work, in order to eliminate the effect of asynchronous clocks and compensate the mobility of sensor nodes. Yan et.al proposed an asynchronous localization algorithm with mobility prediction for active and passive sensor nodes. Simulation result showed that the asynchronous algorithm can effectively eliminate the impact of the clock asynchronization and node mobility [20].

For large-scale localization of AUVs, Melike et.al proposed a localization scheme for UWSNs that did not require a priori infra-structure or synchronization between nodes. Result showed that localization success improved as the duration of the AUV localization process increased and in certain scenarios, the method achieved 100% nodes localized with 3% positioning error [21].

In this paper, we propose and design a localization scheme based on communication signal propagation loss (Figure 2). The rest of the paper is organized as follows. Section 2 explains the model and design of the positioning algorithm, Section 3 presents the experiment and simulation result and Section 4 provides an assessment and comparison of the positioning algorithms. Conclusions are presented in section 5 to summarize the advantages and discuss the open issues of the proposed method.

II. MODEL AND DESIGN OF THE LOCALIZATION SCHEME

In this section, we present a distributed localization scheme for underwater acoustic sensor networks, that is based on the detection of losses in the transmitted signal. The proposed scheme consists of two stages: estimate the distance using the received signal strength of a single carrier sent by the anchor node, and then locate the target node by processing the estimated data. To further explain the proposed scheme, we first define the sound propagation loss.

A. SOUND PROPAGATION LOSS

Like every propagating wave, sound waves lose energy as it propagates with distance. Several reasons affect sound propagation loss and the three main causes are: Spread Loss;

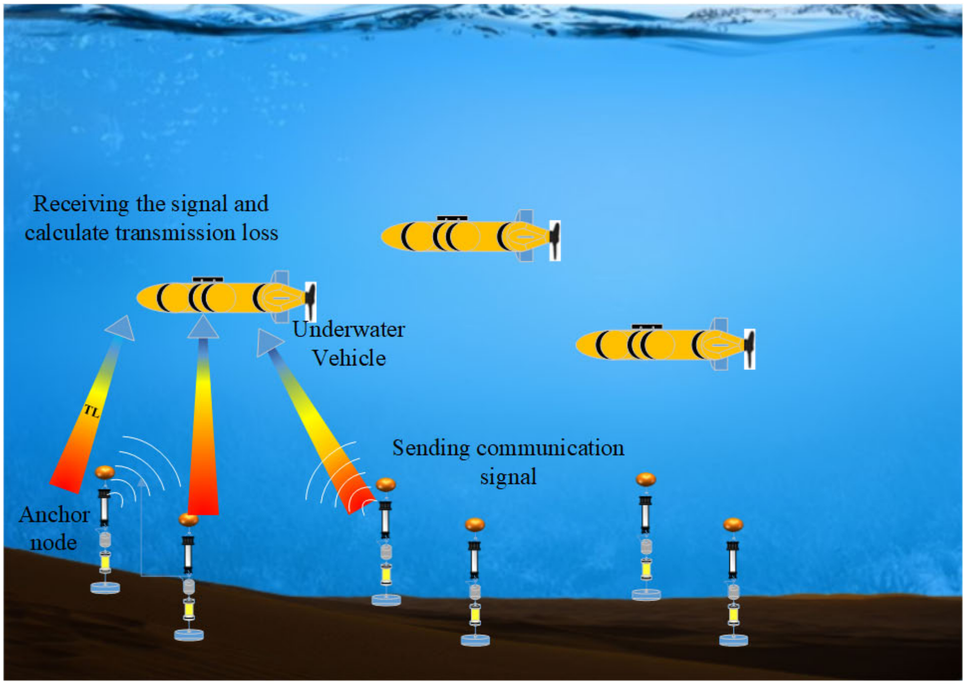


FIGURE 2. Schematic dram for CSPLLS model.

Absorption Loss; and Scattering Loss. Spread loss referred as geometrical attenuation is caused by the extension of wave front leading to reduction in the signal strength. Absorption loss also referred as physical attenuation is caused by medium viscosity, heat conduction and salinity of the medium. The scattering loss is caused by mass of silt, vesicle and plankton which consist of the sea medium.

1) SOUND SPREAD LOSS

In an ideal medium, the sound pressure for an acoustic wave being transmitted in x direction is given in [22] as:

$$p = p_0 \exp[-i(\omega t - kx)] \tag{1}$$

where p_0 is the amplitude of plane wave sound pressure which do not vary with distance x. The plane wave intensity $i \propto {p_0}^2$ also do not vary with x as plane wave front do not expand with propagation distance and, therefore, there is no propagation loss caused by wave front expansion. We use TL_s to represent spread loss, because the sound intensity at distance x equals to the sound intensity at 1m ($I(x) = I(1)$) which is a constant. The expression for the spread loss (TL_s) due to the sound intensity with distance x is the given by:

$$TL_s = 10 \log \frac{I(1)}{I(x)} = 0(dB) \tag{2}$$

So the TL_s of plane wave equals to 0dB in ideal medium.

In another case, when the simple uniformity spherical wave is transmitted along the r vector direction, sound pressure equals to:

$$p = \frac{p_0}{r} \exp[-i(\omega t - kr)] \tag{3}$$

where p_0/r is the amplitude of spherical wave sound pressure and decreases inversely with distance. The intensity $i \propto {p_0}^2/r^2$, so the TL_s for spherical wave equals to:

$$TL_s = 10 \log \frac{I(1)}{I(x)} = 20 \log r(dB) \tag{4}$$

The general expression for the spread loss thus is given by:

$$TL_s = n * \log r(dB) \tag{5}$$

where n is chosen depending on the transmission conditions (shown in Table 1). For most conditions, the spherical wave spreading model is chosen as the classical propagation model in shallow sea [23].

TABLE 1. Value of *n* in different spreading model.

n=0	Plane wave spreading
n=1	Cylindric wave spreading
n=3/2	Correction for cylindric wave spreading with seabed absorption
n=2	Spherical wave spreading
n=3	Spreading through the negative jump layer of sound velocity in shallow water
n=4	correction for spherical wave spreading with sea surface reflection

2) SOUND ABSORPTION LOSS

The sound propagation loss is caused by both absorption and heterogeneous scattering that are co-existed and could hardly be differentiated. Supposing that the plane wave spreads with distance dx, the absorption loss can then be expressed as dI:

$$dI = -2\beta I dx \tag{6}$$

where β is a proportional constant and referred as absorption coefficient [24]. By taking the integral of equation (6) we get:

$$I(x) = I_0 e^{-2\beta x} \tag{7}$$

where I_0 is the initial sound intensity for plane wave at the point, and after applying natural logarithm to equation (7), we get:

$$\beta = \frac{1}{2x}\ln\left(\frac{I_0}{I(x)}\right) = \frac{1}{x}\ln\left(\frac{p_0}{p(x)}\right) \tag{8}$$

where $\ln(p_0/p(x))$ is the natural logarithmic attenuation of the amplitude of sound pressure, referred as Neper. If we represent sound pressure as a base 10 decaying exponential, equation (7) can be written as:

$$I(x) = I_0 * 10^{-\alpha x/10} \tag{9}$$

Then we get:

$$\alpha = \frac{10}{x}\log\left(\frac{I_0}{I(x)}\right) = \frac{20}{x}\lg e * \ln\left(\frac{p_0}{p(x)}\right) = 8.68\beta \tag{10}$$

where α is also named absorption coefficient. So we get the TL_a for sound absorption loss as:

$$TL_a = \alpha r \tag{11}$$

It is to be noted that the absorption loss has frequency selective fading in underwater channel. Absorption coefficient have multiple value models in different channel environments and according to the empirical equation, α can be taken as a prediction absorption coefficient against an unknown environment [25]:

$$\alpha = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 3 * 10^{-4}f^2 + 3.3 * 10^{-3} \tag{12}$$

3) SOUND TRANSMISSION LOSS

When we consider the numerical modeling of the propagation loss, the scattering loss is far less than the spreading loss and absorption loss. Therefore we only sum the spreading and absorption loss as the propagation loss. According to the above derivation in Section 1) and 2) the propagation loss TL then equals to

$$TL = TL_s + TL_a = n * 10\log r + \alpha r \tag{13}$$

In practical situation where CSPLLS is deployed, we need to know the real time channel parameters to choose the value of n and α according to the different conditions before applying the positioning process.

B. SPHERICAL INTERSECTION MATHEMATICAL MODEL TO DETERMINE SOUND SOURCE LOCALIZATION

1) TRILATERATION POSITIONING METHOD

Figure 3 shows a commonly used trilateral positioning method where a target node P(x,y) is localized by the help of three anchor nodes: $A_1(x_1, y_1), A_2(x_2, y_2), A_3(x_3, y_3)$, located at distance r_1, r_2, r_3,respectively from the target node [26].

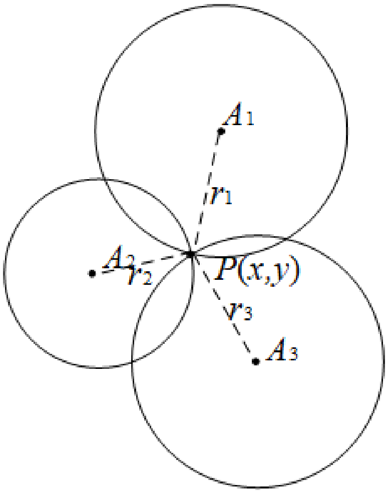


FIGURE 3. Trilateration positioning method.

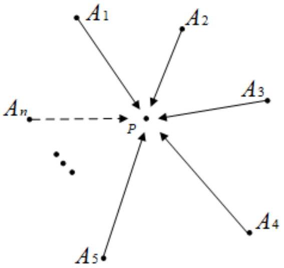


FIGURE 4. Multilateration positioning method.

$$\begin{cases} \sqrt{(x_1 - x_i)^2 + (y_1 - y_i)^2} = r_1 \\ \sqrt{(x_2 - x_i)^2 + (y_2 - y_i)^2} = r_2 \\ \sqrt{(x_3 - x_i)^2 + (y_3 - y_i)^2} = r_3 \end{cases} \tag{14}$$

The target node coordinates can then be find as:

$$\begin{bmatrix} x_i \\ y_i \end{bmatrix} = \begin{bmatrix} 2(x_1 - x_3) & 2(y_1 - y_3) \\ 2(x_2 - x_3) & 2(y_2 - y_3) \end{bmatrix}^{-1} \times \begin{bmatrix} {x_1}^2 - {x_3}^2 + {y_1}^2 - {y_3}^2 + {r_3}^2 - {r_1}^2 \\ {x_2}^2 - {x_3}^2 + {y_2}^2 - {y_3}^2 + {r_3}^2 - {r_2}^2 \end{bmatrix} \tag{15}$$

2) MULTILATERATION POSITIONING METHOD

Figure 4 shows localization of a target node $P(x, y)$ with multiple anchor nodes $A_1(x_1, y_1), A_2(x_2, y_2), A_3(x_3, y_3) \ldots A_n(x_n, y_n)$ at distance $r_1, r_2, r_3 \ldots r_n$, respectively from the target node [27]

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = {r_1}^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = {r_2}^2 \\ \ldots\ldots \\ (x_n - x)^2 + (y_n - y)^2 = {r_n}^2 \end{cases} \tag{16}$$

Simplifying and rearranging the equation (16) we get

$$\begin{cases} {x_1}^2 - {x_n}^2 + 2x(x_1 - x_n) \\ + {y_1}^2 - {y_n}^2 - 2y(y_1 - y_n) = {r_1}^2 - {r_n}^2 \\ {x_2}^2 - {x_n}^2 + 2x(x_2 - x_n) \\ + {y_2}^2 - {y_n}^2 - 2y(y_2 - y_n) = {r_2}^2 - {r_n}^2 \\ \dots \\ {x_{n-1}}^2 - {x_n}^2 + 2x(x_{n-1} - x_n) \\ + {y_{n-1}}^2 - {y_n}^2 - 2y(y_{n-1} - y_n) = {r_{n-1}}^2 - {r_n}^2 \end{cases} \tag{17}$$

Transforming the equation (17) into matrix form yields,:

$$A = 2\begin{bmatrix} x_1 - x_n & y_1 - y_n \\ \dots & \dots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \tag{18}$$

$$B = \begin{bmatrix} {x_1}^2 - {x_n}^2 + {y_1}^2 - \\ {y_n}^2 - {r_1}^2 + {r_n}^2 \\ \dots \\ {x_{n-1}}^2 - {x_n}^2 + {y_{n-1}}^2 - \\ {y_n}^2 - {r_{n-1}}^2 + {r_n}^2 \end{bmatrix} \tag{19}$$

The position coordinates of target node P can then be find using the least mean square error optimal estimation method:

$$\widehat{X} = (A^T A)^{-1} A^T B \tag{20}$$

C. CENTROID OPTIMIZATION ALGORITHM

As mentioned in the section B(1), the commonly used localization method is trilateration and to further improve the accuracy, multilateration is used. But as the underwater medium offers severe multipath and back ground noise, it becomes hard to get high precision with only trilateration and multilateration technique. The result of the equation (16) at times generate multiple solution. To overcome this problem, the triangulation and multilateration techniques are further optimized by applying centroid algorithm to them.

Figure 5 shows the three cases, how centroid algorithm is used in trilateration technique to optimize the localization. The three cases include: 1) when all the three zones intersect with each other, 2) when only one or two of them intersect with each other and, 3) when none of the three zones intersect each other. Q_1, Q_2, Q_3 are three new vertices of the new triangle formed using the centroid algorithm. According to the equation (14) we first find the solution of $Q_1(x_1, y_1), Q_2(x_2, y_2), Q_3(x_3, y_3)$ and then locate the $P(x, y)$ coordinates by equation (21):

$$\begin{cases} x = \dfrac{x_1 + x_2 + x_3}{3} \\ y = \dfrac{y_1 + y_2 + y_3}{3} \end{cases} \tag{21}$$

Similarly, the centroid algorithm is applied to the multilateration technique by introducing $Q_1, Q_2 \dots, Q_n$ virtual intersection points for $A_1, A_2 \dots, A_n$. Using the coordinates of the anchor nodes $A_1(x_1, y_1), A_2(x_2, y_2), \dots A_n(x_n, y_n)$, we get $Q_1(x_q, y_q)$ the virtual positioning intersection point of A_1, A_2, and the distance between Q_1 and A_1, A_2 is d_1, d_2, using following equation:

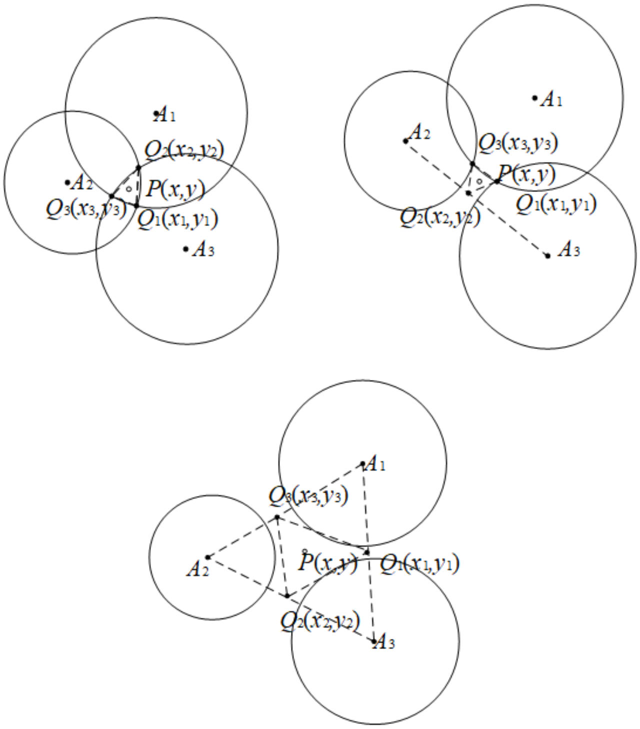


FIGURE 5. Three cases of three anchor nodes centroid optimized positioning method.

$$\begin{cases} (x_q - x_1)/d_1 = (x_2 - x_q)/d_2 \\ (y_q - y_1)/d_1 = (y_2 - y_q)/d_2 \end{cases} \tag{22}$$

By simplifying and rearranging equation (22) and get:

$$\begin{cases} x_q = (x_1/d_1 + x_2/d_2)(1/d_1 + 1/d_2) \\ y_q = (y_1/d_1 + y_2/d_2)(1/d_1 + 1/d_2) \end{cases} \tag{23}$$

Using (22) and (23), the centroid positioning point $P(x_p, y_p)$ by measured distance from anchor nodes $A_1(x_1, y_1), A_2(x_2, y_2), \dots\dots A_n(x_n, y_n)$ is:

$$\begin{cases} x_p = \dfrac{x_1/d_1 + x_2/d_2 + \dots\dots + x_n/d_n}{1/d_1 + 1/d_2 + \dots\dots + 1/d_n} \\ y_p = \dfrac{y_1/d_1 + y_2/d_2 + \dots\dots + y_n/d_n}{1/d_1 + 1/d_2 + \dots\dots + 1/d_n} \end{cases} \tag{24}$$

where $1/d_i$ is the weight of the influence on the distance information received by anchor node i.

D. IMPLEMENTATION DETAILS

We now present the design of the proposed localization scheme. The localization of the target node is performed in two stages. In first stage, the distance between the anchor nodes and the target node is calculated using the sound propagation loss model. The second stage then uses the distance information, apply the centroid optimization and perform localization. The proposed scheme is also low power as it does not require additional clock information used in traditional localization schemes.

a: DESIGN FOR THE COMMUNICATION SIGNAL

To communicate between the anchor node and the target node we chose a single tone. We further use spread spectrum technique for the communication to overcome the severe physical challenges of underwater acoustic medium.

Spread spectrum communication (SSC) have a low peak-to-average power ratio (PAPR) that offers a stable attenuation in underwater channel. Besides, SSC have high concealment and strong anti-interference ability. The receiving signal can get a spread spectrum gain and able to communicate in low signal noise ratio (SNR).

b: DESIGN FOR THE POSITIONING PROCESS

According to the principle of the signal propagation loss and localization method, we design the communication signal propagation loss localization scheme. The positioning process of CSPLLS can be divided into three stages.

Assuming that the target is an AUV as an example. In the first stage, we need to measure the environmental parameters and channel models, including the sound spread model and absorption coefficient. We complete this stage with a short distance propagation loss measurement in the positioning environment. After the measurement of basic parameters, in the second stage, an AUV target send its communication and positioning instructions to each anchor node. The anchor node after receiving the instructions then transmits the message containing the strength of the signal along with the information data. In stage 3, AUV receives the communication signal from each anchor node, measures the received signal strength and calculates the transmission loss. Then AUV target calculates the position by positioning equation (24) and the process is shown in Figure 6.

III. RESULTS AND DISCUSSION

As mentioned in Section II we first find the distance using the propagation loss model and then use the distance measurement to locate the target node with trilateration and centroid algorithm. In this section, we present the results of our experiments and simulation and describe the performance of our proposed algorithm.

A. FINDING DISTANCE WITH PROPAGATION LOSS MODEL:

We performed both underwater experiments and simulations to calculate the distance based on the propagation loss of the signal and compared the error. We conducted our underwater localization experiments in Songhua River Heilongjiang Province China in December 2018 (Figure 7). We used two ships as the transmitting and receiving places. We used 6-12kHz transducer to transmit spread spectrum signal with a central frequency of 8kHz. The signal was received by one standard hydrophone. The distance between the transmitter and the receiver was set to 10 km.

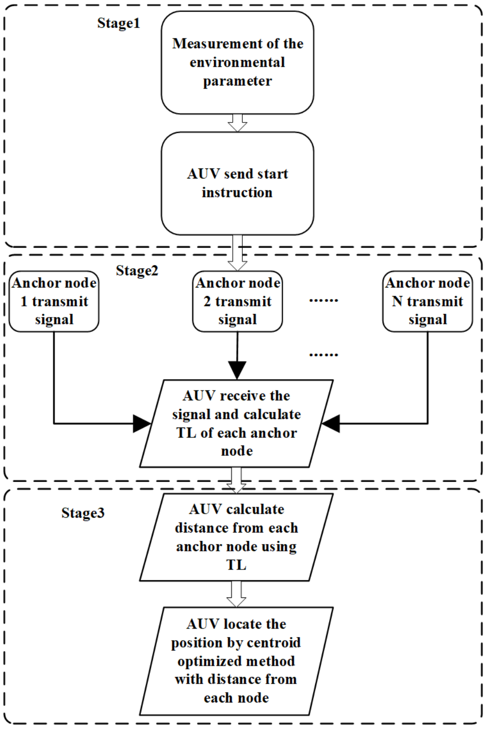


FIGURE 6. Process of CSPLLS applicated in AUV positioning.

FIGURE 7. Satellite map and scenes for the experiment.

To transmit the signal with high power (> 190dB) we used a power amplifier of 2000W. After connecting the hydrophones with the circuitry, we first measured the transmitting sound level using the Bruel & Kjaer 8105 standard hydrophone at 1 meter and the signal strength was recorded as 193.7dB. To get sufficient data, we set the transmitter to send 50 set of 500msec long signal with gap of 1 second.

On the receive side, the mean signal power was first measured and then translated to dB. The data was recorded at 1Km, 2Km,. . .,10Km for each 1Km recorded once. Figure 8 shows the transmission loss versus distance measured by the underwater experiments and the simulation using the absorption coefficient. The x-axis represents the sound transmitted distance and the y-axis represents the signal transmission loss. We calculated the theoretical propagation loss with sound frequency and absorption coefficient using equation (12) for each distance and print the simulation results in Figure 8. Then we calculated the mean experimental propagation loss for each distance from 1Km to 10Km. It can be noted that the experiment results are uniformly distributed on both sides of the theoretical curve, and by precise calculation, the mean square error of TL equal to 3.0dB in this experiment.

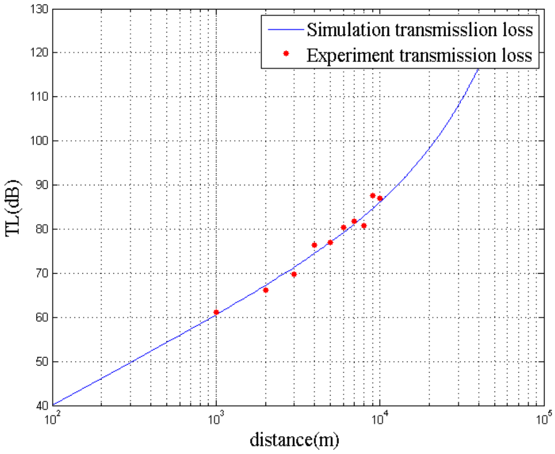
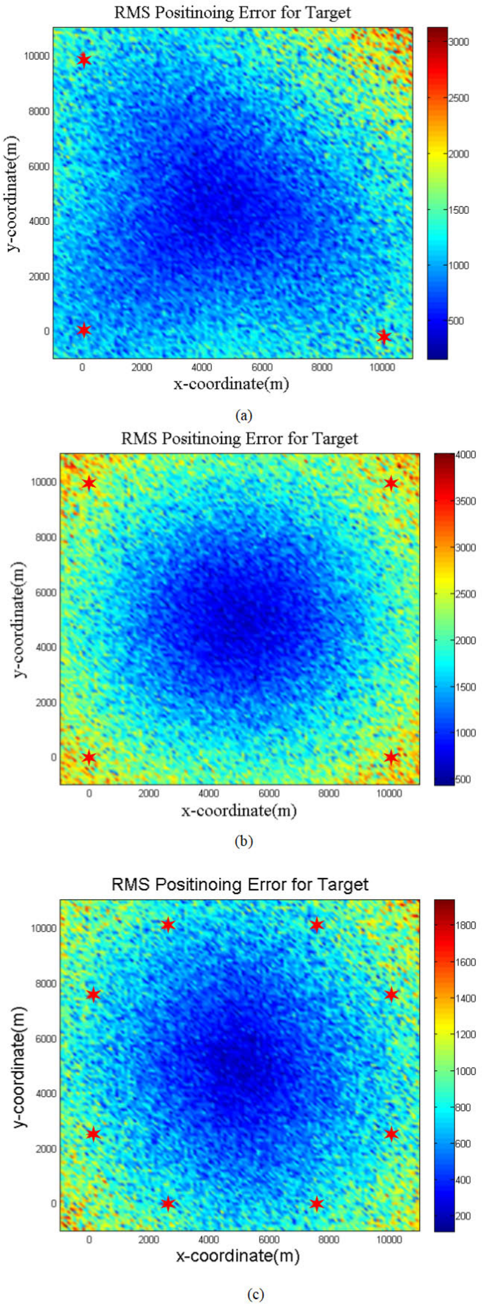


FIGURE 8. **Signal propagation loss-distance simulation and experiment results.**

B. PROPAGATION LOSS-DISTANCE ERROR BASED LOCALIZATION SIMULATION

In the second part, we evaluated the proposed method using the simulation by MATLAB. We set the simulation parameters to let the target in similar water conditions as the river experiment, and able to move in a 10km × 10km area. We both simulated for trilateration positioning method and multilateration positioning method and took different number of anchor nodes (3, 4 and 8) to localize the target. Besides, the spherical intersection and centroid optimization algorithm are also simulated in this section. We calculated the real distance through the coordinates of target node and anchor nodes and calculated the transmission loss by equation (13). According to the experiment results in section III A, a 3.0dB gaussian random error was added to the TL as the simulation data. Then we used TL to calculate the distance and positioning.

1) SPHERICAL INTERSECTION METHOD:



(a)

(b)

(c)

FIGURE 9. **Positioning error for spherical intersection method: (a) 3 anchor nodes; (b) 4 anchor nodes; (c) 8 anchor nodes.**

We started with three anchor nodes fixed at (0, 0), (0, 10000), (10000, 0) in Figure 9(a), the red points represents the position for each anchor node. The x-axis and the y-axis represents the distance of which one point equals to 1 meter.The target node was placed at (0,0) as the initial point and then moved 500 meters a time along the x-axis and y-axis to cover the whole area (10k × 10k) and located at each point. The target node is localized by taking root mean square (RMS) error of ten readings at each point. The simulation results by pseudo-color map are shown in Figure 9(a). We can get the positioning error trend of the area from the color distribution and read the specific error value from the color-bar of each point. The positioning accuracy of central area is much higher than that of the edge area by color contrast. We referred the (5000, 5000) as the central point of the area. It can be seen that the positioning RMS error near the central point is close to 500m. Furthermore, it can be seen that the localization accuracy significantly decreases when the target node is either close to one of the anchor nodes or far away from all anchor nodes. This significant decrease is due to large error of one of the anchor node overshadowing the smaller error of the other nodes. To reduce this effect, we increased the anchor nodes to 4 and 8 to use multilateration positioning method and perform the experiments. The results are shown in Figure 9(b) and Figure 9(c) respectively. It can be seen that with increase in number of nodes, there is a remarkable improvement in the localization accuracy. The error in the center region has reduced from 500 meters to 200 meters.

2) CENTROID OPTIMIZED METHOD:

In order to further improve the positioning accuracy, we used centroid positioning algorithm to optimize the CSPLLS. We designed the centroid algorithm simulation and target was located by 3, 4 and 8 anchor nodes which cover the 10km × 10km the same as simulation in spherical intersection method. Results by pseudo-color are shown in Figure 10 (a), (b) and (c). Similar error trend appears in Figure 10 and there is a significant decrease in the data of color bar. Compared with Figure 9, the positioning accuracy has a huge improvement when the target is near the central point, as the positioning error can be decreased to about 100m with 8 anchor nodes using centroid optimized method. There is also improvement in positioning accuracy near the edges to a good extent.

To analyze the positioning accuracy with the increase in anchor nodes, vertically compare the positioning accuracy of Figure 9(a), (b), (c) and Figure 10(a), (b), (c), it can be seen that the positioning accuracy has an obviously improvement with the increase of the number of anchor nodes. The localization error reduces when the target get distance information from more anchor nodes. When horizontally compared Figure 9 and Figure 10, it can be seen that the centroid optimized method provides better accuracy compared to the spherical intersection method.

To further compare the positioning results of spherical intersection method and centroid optimized method, we selected a random point nearby the central point and located 20 times for each 3, 4 and 8 anchor nodes. Figure 11 (a),(b) and (c) shows the result and it can obviously be seen that the centroid optimized method has a huge improvement in positioning accuracy.

According to Figure 9 and Figure 10, we divided the whole region into central area of 3000m from the central point, and edge area (3000m away from the central point). We calculated the mean absolute error and the percentage error for above situation in section B and the data was summarized in table 2. According to experiment and simulation results, the highest accuracy of our proposed method can reach to 155m and 2.2% in 10km × 10km area.

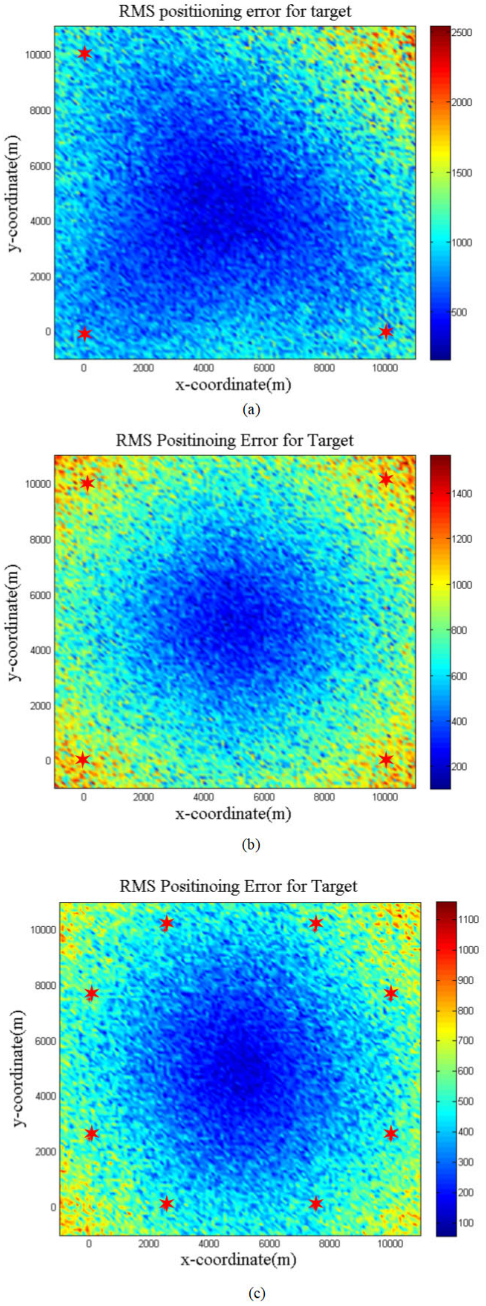
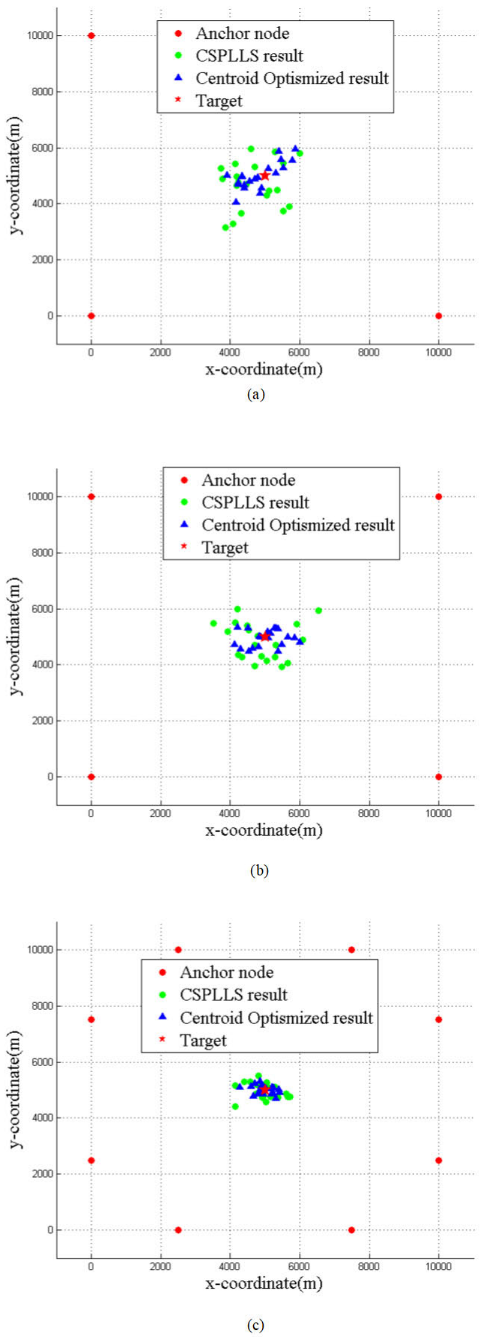


FIGURE 10. **Positioning error for centroid optimized method: (a) 3 anchor nodes; (b) 4 anchor nodes; (c) 8 anchor nodes.**

IV. EFFECTIVENESS AND CHALLENGES OF CSPLLS

We believe that our proposed method (CSPLLS) is suitable for multi-target and large-scale localization especially for AUVs positioning and localization in shallow sea. CSPLLS have achieved these following effectiveness:

The CSPLLS is a signal strength-based localization method which can realize the underwater communication and



(a)

(b)

(c)

FIGURE 11. Random point positioning error for xoherical intersection method and centroid optimized method: (a) 3 anchor nodes; (b) 4 anchor nodes; (c) 8 anchor nodes.

localization integration. CSPLLS do not use clock resources in this method and got rid of got rid of the clock dependence as used in traditional range-based localization method resulting in reduced power consumption for both locating target and the anchor nodes. Meanwhile, CSPLLS can prolong the lifetime of underwater nodes and networks.

TABLE 2. Distance error and percentage error for spherical intersection and centroid optimized method for anchor nodes (Na):3,4,8.

	Central positioning error(m)	Percentage error	Edge positioning error(m)	Percentage error
Na=3 spherical intersection	547	7.7%	1026	12.0%
Na=3 centroid optimize	509	7.2%	858	10.0%
Na=4 spherical intersection	496	7.0%	908	10.6%
Na=4 centroid optimize	328	4.6%	597	6.1%
Na=8 spherical intersection	268	3.5%	458	5.3%
Na=8 centroid optimize	155	2.2%	236	2.6%

Compared with the TOA and TDOA method, CSPLLS can achieve localization with with a single message exchange between the anchor nodes and the target node and do not need synchronization process used in TOA and TDOA. This simplifies the complexity of the network and therefore achieves quick positioning of the target.

The positioning accuracy for CSPLLS can further be improved by adding more number of anchor nodes for applications that require long distance and large scale positioning.

Apart from the mentioned advantages of CSPLLS there also exists a few challenges:

As CSPLLS highly depends on the signal transmission environment such as sound spreading model and absorption coefficients, it becomes important to know the environment parameters in advance otherwise, the positioning accuracy will greatly be effected.

In CSPLLS, target node need to get the direct signal from each anchor node. When the direct signal is blocked, or the received signal is affected by multipath, direct sound can be hardly received or separated from the stack signals. So the positioning accuracy decreased seriously by the abundant shielding around the target.

On account of the different transmission characteristics for vertical channel axis and horizontal channel axis, the numerical value is different for propagation loss in same distance transmitting from horizontally and vertically. So it is open issues for the CSPLLS applied to deep-ocean localization.

V. CONCLUSION

In this paper, we have presented a Communication Signal Propagation Loss Localization Scheme (CSPLLS) that can achieve communication and positioning synchronization. By the transmission loss-distance based CSPLLS, locating target can use the communication signal strength information to calculate the distance from at least three anchor nodes and accomplish positioning process. Focusing on the propagation loss measurement error caused by each anchor node, a centroid optimized CSPLLS is proposed. The simulation results show that CSPLLS can provide a reasonable precision for 10km × 10km area and by centroid optimized method, there have a significant improvement in positioning accuracy and positioning coverage rate which can reach as low as 2.2% positioning accuracy. Compared with the positioning method for AUVs in [21], CSPLLS can implement the same level of localization accuracy of with a lower network cost. With the CSPLLS, multiple target and large-scale localization in neritic region have obvious advantages with quick localization by single signal transmission ranging. In addition, the energy consumption is also reduced by not utilizing the clock resources in positioning process. The proposed localization method thus is highly applicable for UUV and AUV operating in environmental monitoring and target navigation for UWSNs.

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GANG QIAO received the B.S., M.S., and Ph.D. degrees from the College of Underwater Acoustic Engineering, Harbin Engineering University (HEU), China, in 1996, 1999, and 2004, respectively, where he is currently a Professor and the Associate Dean with the College of Underwater Acoustic Engineering. Since 1999, he has been with the College of Underwater Acoustic Engineering, Harbin Engineering University. He has already published more than 80 papers and owned seven national invention patents. His current research interests include underwater communication and networks, detection and positioning of underwater targets, and the sonar designed for small carriers. He is currently a member of Acoustical Society of China, a member of the Youth Federation of Heilongjiang Province, and the Vice Chairman of Robotics Society of Heilongjiang Province. He received the National Award for the Outstanding Scientific and technological workers and the Science Technology Award for Young Talents, Heilongjiang.

CHEN ZHAO was born in Harbin, China, in 1993. He received the B.Sc. and M.Sc. degrees from the College of Underwater Acoustic, Harbin Engineering University, in 2015 and 2016, respectively. His currently worked on lower power method for underwater cooperative target navigation and localization, such as UUVs and AUVs. His research interests include in the underwater spread spectrum communication and underwater cooperative navigation and localization rely on underwater sensors networks, particularly in distributed underwater localization.

FENG ZHOU received the B.S. and M.S. degrees in communication and information system from Jilin University, China, in 2002 and 2005, respectively, and the Ph.D. degree from the College of Underwater Acoustic, Harbin Engineering University (HEU), where he is currently an Associate Professor. Throughout, his career he has worked on primarily on underwater acoustic communications. His current research interests include underwater acoustic spread spectrum communications, underwater acoustic multi-carrier communications, localization in underwater networks, and underwater acoustic modem development. In 2013 and 2015, he received ‘‘National Natural Science Foundation’’ Award to design efficient communication solutions for underwater applications.

NIAZ AHMED received the B.S. degree in telecommunication engineering from NUCES-FAST University, Lahore, Pakistan, in 2010, the M.S. degree in computer engineering from CASE University, Islamabad, Pakistan, in 2012, and the Ph.D. degree in electrical engineering from the Missouri University of Science and Technology, Rolla, MO, USA, in 2017. He is currently an Associate Professor with Harbin Engineering University, Harbin, China. His research interests include wireless communication, underwater wireless sensor networks, and embedded systems.

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