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# A Study on the Application of WSN Positioning Technology to Unattended Areas

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**ABSTRACT** Wireless sensor network (WSN) is a kind of self-organized network that plays a critical role in the rescue and relief work of some unattended areas in recent years. With the application background of unattended areas, a positioning algorithm with high accuracy and coverage in the WSN is presented in this paper. First, in view of the complicated environment in unattended areas and demand for accurate positioning, this paper focuses on the ranging-based positioning technology, introduces double-hop ranging in the Euclidean algorithm into the 3D ranging process at the node, and proposes 3DL positioning algorithm on this basis. This proposed algorithm is able to achieve 3D positioning of network nodes and effectively enlarge the network positioning coverage by upgrading the positioned node with adequate accuracy to proxy anchor. Second, since unattended areas are mostly non-line-of-sight (NLOS) environments and node positioning accuracy is affected by NOLS factors, a 3DL-N positioning algorithm is proposed by introducing the way of making up for node positioning error based on the 3DL algorithm. The algorithm makes use of the relative positioning function of anchors to figure out the ranging correction parameter and node positioning error compensation value and adds it to the positioning process of the common to further improve its positioning accuracy. Finally, the simulation results indicate that the positioning algorithm proposed in this paper enjoys significant strengths in terms of positioning accuracy and coverage on the premise of consuming no higher node energy.

**INDEX TERMS** Positioning accuracy, positioning algorithm, wireless sensor network (WSN).

## I. INTRODUCTION

As microelectronic technology and embedded technology keep proceeding and wireless communication gets updated day by day, wireless sensor network (WSN) gradually enters the vision of general public and goes increasingly mature. All the nodes in WSN are equipped with such functions as environment perception and data processing, so they can collaborate with each other to send the acquired monitoring information to the observer so as to establish the ternary relationship among sensor, monitoring object, and observer. WSN is characterized by its small node size, low cost, high adaptability and reliability, it is widely applied to a variety of industries, including military and national defense, environment monitoring, medical care, and target tracking, as well as some unattended areas in recent years. A wireless communication network can be created with those sensor nodes deployed in such areas to achieve the goal of monitoring and early warning. Compared with traditional applied environments, unattended areas feature harsh natural environment, rugged surroundings and improper stationing conditions. The real-time monitoring in such areas can effectively reduce the personal casualty and economic loss resulting from natural disasters, which is of great significance for the society.

Node positioning technology [1]–[3] plays a critical role in the monitoring activities of WSN, and it is an important indicator for measuring the practicability of WSN application. This is especially true in the unattended environments where it is usually impossible to artificially deploy sensor nodes and massive random dispersion is adopted instead. In such case, node positioning remains as a key to the effectiveness of sensor network application. In the present stage, the mainstream outdoor positioning systems used widely at home and abroad are GPS and Beidou. Although every sensor node

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can be provided with a GPS or Beidou positioning module to realize self-positioning, it will greatly raise the cost of network positioning system. This contradicts the low-cost feature of sensor network and fails to meet the application demand. Therefore, to equip a few wireless sensor nodes with positioning module to achieve self-positioning and then make use of node positioning algorithm to determine the position information of other nodes is not only significant in theoretical research but also quite valuable in practice. In light of the analysis above, with the application to unattended areas as the background, this paper analyzes the existing positioning technologies and proposes WSN 3D positioning algorithm and then achieves effective self-positioning of nodes in non-line-of-sight (NLOS) environment.

The rest of the paper is organized as follows. Section II introduces the research status at home and abroad. Section III gives the related definitions used in this paper. Section IV proposes the range-based 3D positioning algorithm. Section V presents the NLOS positioning algorithm. Section VI reports the algorithm simulation results. Concluding remarks and future directions are put forward in Section VII.

## II. THE RESEARCH STATUS

WSN can be traced to the strategic demand of overseas military projects. It is first proposed by foreign scholars in 1990s, and multi-dimensional studies are carried out in this field afterwards. As the studies go deeper and deeper, its scientific significance and commercial value gradually stand out and it gets penetrated to the civil fields slowly while gaining more attention and massive application both at home and abroad. Extensive research involving different fields is thus established. The military powers and powerful nations of science and technology around the world have drafted state-level research policies and strategies targeting WSN and keep paying high attention to it. Since this century, some experts and scholars in the world have successively presented many node positioning algorithms for WSN. These algorithms can be divided as follows:

### A. RANGE-FREE POSITIONING VS. RANGE-BASED POSITIONING

Needing not measure the distance between different nodes, range-free positioning algorithms [4] usually set to compute the location of a common on the basis of the geometric relationship and coordinate of a few known nodes. By comparison, the range-based [5], [6] positioning algorithms mainly adopt certain ranging techniques to figure out the relative distance between network nodes and then the common coordinate calculation methods to find out the specific coordinates of the common.

In the category of range-free positioning algorithms, there are DV-Hop [7], APIT [8], centroid localization algorithm [9]. Among them, APIT and centroid localization algorithm can be classified as geometric constraint algorithms, for both of them are based on polygon positioning principle which means the coordinates of to-be-positioned node can be approximated with the center or centroid of the polygon constituted by some known nodes when it is located within this area. Range-free positioning algorithms are a kind of lowly accurate positioning method which demands no auxiliary positioning device and features simple computation, low communication traffic and node power consumption. They are usually used to assist the range-based positioning algorithms in practical application.

Range-based positioning algorithms achieve network positioning mainly through certain ranging techniques and information about positioned nodes. The values to be measured in ranging techniques usually include time of arrival (TOA) [10], time difference of arrival (TDOA) [11], [12], angle of arrival (AOA) [13] and received signal strength indicator (RSSI) [14], [15]. Although demanding higher hardware configuration at sensor node and some auxiliary positioning devices, the range-based positioning algorithms are able to accomplish highly accurate positioning and are thus more widely applied. Based on the comparison of those two algorithms, this paper focuses on the range-based positioning algorithms.

### B. CENTRALIZED POSITIONING VS. DISTRIBUTED POSITIONING

For centralized positioning, the central node of the network lies at the core of whole algorithm, which can be used to compute the coordinates about all the nodes. Such kind of design is simple in thought, and relatively accurate in node coordinate positioning, but its weaknesses remain also evident. First of all, as central node is critical to the coordinate data computation for all the nodes in the network, high computation and storage capacities are required. Secondly, the high computation at central node will cause greatly increased power consumption so that more power supply devices should be provided. Finally, all the nodes not positioned yet need to send their information to the central node, causing such problems as network communication congestion and low data fusion. Moreover, the excessive workload on central node and its neighboring nodes can also lead to premature failure of them in the network. Those weaknesses substantially limit the promotion and application of this positioning algorithm. Convex optimization [16], [17] is the most frequently used centralized positioning algorithm at the present stage.

Distributed positioning algorithm is a kind algorithm in which nodes exchange information and collaborate with each other to achieve the positioning process. It is designed to average the assignments of central node in centralized positioning algorithm to all the nodes in the network so as to effectively extend the life cycle of the network. When compared with centralized positioning algorithm, it is more in line with practical need and becomes the mainstream WSN node positioning technology in recent years. At present, the frequently used distributed positioning algorithms mainly include DV-Hop [18]–[20] and DV-Distance [21]. Based on a comparative analysis of those two kinds of algorithms, this paper decides to focus on the study on distributed positioning algorithm.

### C. CONCURRENT POSITIONING VS. INCREMENTAL POSITIONING

Concurrent positioning algorithm requires concurrent activation of positioning function of all the nodes from a certain moment. In this algorithm, the anchors in the network must be able to directly establish single-hop communication with all the nodes or there are sufficient anchors that can communicate with the whole network. Its merits lie in the easily comprehensible design, low average energy consumption with network node positioning being completed by all the anchors, and high positioning accuracy, while its demerits include demand for sufficiently high transmitting power of anchors or high number of anchors which greatly raises the cost of network positioning and may lead to insufficient power supply for the nodes with increased transmitting power and energy consumption by anchors. Concurrent positioning algorithm is a sort of idealized positioning algorithm.

Starting from anchors, incremental positioning algorithm gradually extends outwards to complete the positioning. Compared with concurrent positioning algorithm, it can complete the positioning of whole network with lower ratio of anchors. However, the positioning accuracy of this algorithm is relatively low and the positioning time is relatively long In specific engineering projects, repeated verification is needed as per practical need in order to determine the ratio of anchors and find out a balance point between positioning accuracy and systematic cost. This paper selects incremental positioning algorithm as the research object after analyzing and comparing those two types of algorithms.

### D. RELATIVE POSITIONING AND ABSOLUTE POSITIONING

With relative concept as the core thought, relative positioning algorithm doesn't need global positioning system to determine its geographical location. For any common, its relative coordinates can be figured out with the artificially set central node in WSN as the reference. This algorithm has such advantages as simple design and low cost and thus can be applied to scenarios where only relative coordinate information is needed. Nevertheless, its disadvantage is equally obvious, namely its limited use to sensor network positioning system demanding no absolute coordinates.

Absolute positioning algorithm is a kind of positioning algorithm that is used to compute the accurate geographical coordinates in standard coordinate system or artificially designated position coordinates. Compared with relative positioning algorithm, the absolute one can better deal with those practical issues and thus has wider scope of application. By now, the mainstream positioning technologies are dominated by absolute positioning technology. Both relative and absolute positioning algorithms are indispensable, for they play their own roles in proper scenes of application. After a comparative analysis of them, this paper adopts absolute positioning algorithm as one of research objects.

China falls behind the foreign countries in WSN-related studies due to a late start. In 2006, WSN is included in the top ten emerging important research fields by the state; and in 2009, the Ministry of Industry and Information Technology established Chinese Sensor Network Standardization Team to take charge of the research and creating standards about WSN and determine direction for the industrial application of WSN within the country. Furthermore, many colleges, enterprises and research institutions enter the queue of research in this field under the incentive of encouraging national policies and increased scientific research fund, and a lot of achievements have been made. Reference [22] reviewed and analyzed all sorts of WSN positioning algorithms; Reference [23] applied Kalman filtering and its extended version to WSN target tracking and compared their positioning accuracy; Reference [24] studied the NLOS state discrimination algorithm based on strict residual selection mechanism, and suggested extended Kalman filtering algorithm at sensor node to compute the mobile target tracking in NLOS environment; Reference [25] came up with a neural network (NN)-based WSN forest fire prevention technique. Besides, due to the colossal commercial and social use value behind WSN, some domestic scientific research institutions and companies in China have initiated more substantive studies and experiments about it. Wider application prospect becomes obvious in such security and protection fields as disaster relief and mine safety monitoring.

Generally speaking, the research work concerning WSN self-positioning technology keeps advancing and considerable progress has been made under the efforts of domestic and foreign scholars in the past decade. However, the positioning algorithms in this stage are mostly based on 2D positioning and it is difficult to well integrate the low network cost and high positioning accuracy of WSN. As for practical engineering, there is still space for further exploration in applying WSN to unattended areas.

In view of those factors, this paper sets the unattended areas as the primary application background and attempts to figure out the way of achieving higher node positioning accuracy and network positioning coverage on the premise of maintaining low network cost. On the basis of going deeper into the WSN node positioning algorithms, it compares the pros and cons of existing node positioning algorithms and comes up with the WSN 3D positioning algorithm. This algorithm can realize 3D positioning of network nodes, upgrades the proxy anchors to enlarge the network positioning coverage, and endow the updated anchors with different weights to compute the coordinates of commons so as to raise the positioning accuracy of the network nodes. In view of the circumstantial characteristics of unattended areas, the positioning algorithms may be affected by a string of NLOS conditions such as multipath transmission and signal attenuation. Based on the 3D positioning algorithm, this paper also introduces node positioning error compensation by figuring out first the error through relative positioning function of anchors in combination with geometric computation and then adding the error to the positioning process of common in order to further improve the positioning accuracy of the algorithm.

## III. RELATED DEFINITIONS

The definitions of terminologies mentioned in this paper are provided below:

**Anchor** means the node provided with Beidou satellite positioning device or artificially set and deployed with geographical location information. Such kind of nodes occupies a low ratio in the sensor network, and they have known geographical coordinates as soon as being started to work.

**Common** is the common node without Beidou satellite positioning device or artificially designated geographical coordinates. Such nodes have no known geographical coordinates when starting to work; instead their geographical coordinates have to be computed on the basis of the location information provided by sufficient number of anchors within the communication range as well as the system node positioning algorithm.

**Pro_Anchor** remains common in early stage but can act as an anchor to provide geographical location information for other commons in the network after its coordinates are figured out as per system positioning algorithm and it meets the positioning accuracy requirement.

**Line-of-sight (LOS)** means linear transmission of wireless signals in which two ends of communication are within the vision.

**Non-line-of-sight (NLOS)** means the non-linear transmission of wireless signals with two ends being blocked from vision.

**Positioned node** is the node with known geographical coordinates, including both anchor and proxy anchor.

**Node upgrading** means the process in which common becomes proxy anchor.

## IV. RANGE-BASED 3D POSITIONING ALGORITHM

With unattended areas as the application background, in this paper, range-based positioning technology with high positioning accuracy is selected, and the key technologies of node 3D positioning and NLOS positioning are mainly considered.

Focusing on the 3D positioning technology for WSN nodes, this section puts forward 3DL positioning algorithm by referring to the double-hop ranging thought in Euclidean algorithm.

What distinguishes Euclidean algorithm from other range-based positioning algorithms is exactly its ability in conducting double-hop node ranging which is beyond comparison by other algorithms. This paper refers to the double-hop node ranging idea of this algorithm and applies it to the 3D node positioning of WSN when proposing 3DL positioning algorithm. Next, we will talk about the node ranging and coordinate computation of the algorithm in details.

### A. 3D NODE RANGING

This paper adopts maximum likelihood estimation (MLE) method in solving the coordinates of any common. Suppose the coordinates of a common is $(x, y, z)$ and those of $n$ anchors are $(x_1, y_1, z_1)$, $(x_2, y_2, z_2) \ldots (x_n, y_n, z_n)$, and $d_1, d_2, \ldots d_n$ indicate the distances of the common from $n$ known nodes,

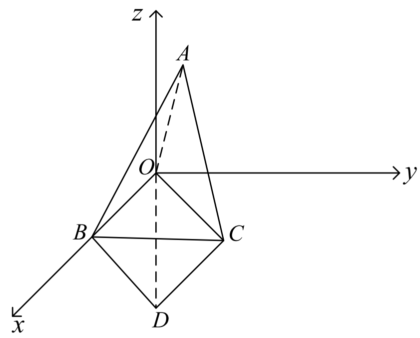


**FIGURE 1.** The diagram of 3D node.

(1) can be established:

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = d_1^2 \\ \vdots \\ (x-x_n)^2 + (y-y_n)^2 + (z-z_n)^2 = d_1^n \end{cases} \tag{1}$$

After each equation in (1) is subtracted with the last equation and the quadratic term is eliminated, (2) will be obtained:

$$AX = B \tag{2}$$

where

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

$$B = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_n^2 - d_1^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{bmatrix},$$

$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix}.$$

Solution to (2) is (3):

$$X = (A^T A^{-1})\, A^T B \tag{3}$$

Fig. 1 demonstrates the double-hop ranging principle under 3D positional algorithm.

As shown in Fig. 1, suppose $A$ is an anchor while $D$ is a common with coordinates to be determined, double-hop communication between nodes $A$ and $D$. Nodes $O$, $B$ and $C$ are the neighbors of both anchor $A$ and common $D$ which are next to each other also.

Suppose node $O$ is the origin of coordinate axes, the straight line where nodes $O$ and $B$ are located is $x$ axis and the plane where nodes $O$, $B$ and $C$ are located is the plane on which $x$ and $y$ axes intersect with each other, a 3D coordinate system can be thus established. The distance from node $A$ to node $D$ can be figured out as follows.

Because node $A$ is adjacent to nodes $O$, $B$ and $D$ at the same time, the distances between nodes $A$ and $O$, $A$ and $B$, and $A$ and $C$ can be computed. Likewise, nodes $O$, $B$ and $C$ are adjacent nodes while node $D$ is next to nodes $O$, $B$ and $C$, the distances between nodes $O$ and $B$, $O$and $C$, and $B$ and $C$ as well as nodes $D$ and $B$, $D$ and $C$, and $D$ and $O$ can be speculated. Suppose the coordinates of node $O$ are (0, 0, 0), that of node $N$ are ($OB$, 0, 0), and that of node $C$ are ($x_c$, $y_c$, 0), then (4) will be satisfied.

$$\begin{cases} c\left(x_c^2 - OB\right)^2 + y_c^2 = BC^2 \\ x_c^2 + y_c^2 = OC^2 \end{cases} \tag{4}$$

Solve (4), and get (5), as shown at the bottom of this page, where the value of $y_c$ in (5) will not affect the length of$AD$ in any way, for it affects only the positioning of node $C$ in the 3D space. Suppose the coordinates of anchor $A$ are ($x_a$, $y_a$, $z_a$) ($z_a$ >0), (6) is generated:

$$\begin{cases} x_a^2 + y_a^2 + z_a^2 = AO^2 \\ (x_a - OB)^2 + y_a^2 + z_a^2 = AB^2 \\ (x_a - x_c)^2 + (y_a - y_c)^2 + z_a^2 = AC^2 \end{cases} \tag{6}$$

Solve (6), and get (7), as shown at the bottom of this page. Now that the distances of $OD$, $BD$ and $CD$ are known already, the coordinates of node $D$ ($x_d$, $y_d$, $z_d$) can be figured out in the same way. Equation (8) results from the equation for computing the distance between nodes:

$$AD = \sqrt{(x_a - x_d)^2 + (y_a - y_d)^2 + (z_a - z_d)^2} \tag{8}$$

Equation (8) involves arithmetical square root, two values of $AD$ will be produced as shown in Fig. 2:

The final calculated $AD$ distance can be $AD$ or $AD\prime$ in Fig. 2. Because anchor $A$ and common $D$ are not neighboring nodes, double-hop is needed to establish communication and this means the length of $AD$ must be one time longer but two times shorter than the communication radius of the node. When both $AD$ and $AD\prime$ meet the aforesaid condition, a neighboring node that can substitute node $O$, $B$ or $C$ should be found within the communication scope of node $D$ and again two $AD$ values will be deducted through the computational process above, and the average of two approximate values among four $AD$ values will be set as the final value of $AD$. After the distances of node $D$ from at least anchors are figured out, its position will be determined as the coordinate computation method in 3D space.

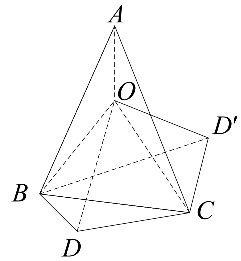


**FIGURE 2.** Two values of AD length in a 3D space.

### B. UPGRADING TO PROXY ANCHOR

In distributed positioning algorithm, a common in the network will be automatically upgraded to a proxy anchor and used in the position computation process of other commons after its coordinates are figured out. Since there may be an error in the coordinates of common resulting from the computation, greater error will be caused in the coordinates of other commons after it is directly updated to proxy anchor and used in the coordinate determination of such commons. In such case, error gets accumulated.

To solve the problem above, the effectiveness of the algorithm must be improved by setting a threshold for the positioning accuracy. A common can only be upgraded to a proxy anchor only when its positioning accuracy with known coordinates reach the threshold requirement; or else the node will still be used as a common one. The solving process and values of the node accuracy threshold will be given below.

### C. WEIGHTING OF COORDINATE COMPUTING PROCESS

Anchors or proxy anchors are required in solving the coordinates of a common. Due to the difference in positioning accuracy of anchors or proxy anchors, their trust weights should be calculated. The trust weight of an anchor is set to be 1, while that $v_p$ of a proxy anchor can be figured out by (9):

$$v_p = 1 - \frac{\sum\left(\sqrt{(x_p - x_i)^2 + (y_p - y_i)^2 + (z_p - z_i)^2}\right) - d_{pi})}{\sum\sqrt{(x_p - x_i)^2 + (y_p - y_i)^2 + (z_p - z_i)^2}} \tag{9}$$

$$\begin{cases} x_c = \dfrac{OB^2 + OC^2 - BC^2}{2OB} \\ y_c = \pm\dfrac{\sqrt{(OB + OC + BC)(OB + OC - BC)(OB - OC + BC)(OC - OB + BC)}}{2OB} \end{cases} \tag{5}$$

$$\begin{cases} x_a = \dfrac{AO^2 - AB^2 + OB^2}{2OB} \\ y_a = \dfrac{AO^2 - AC^2 - 2x_a x_c + OC^2}{2y_c} \\ z_a = \sqrt{AO^2 - \dfrac{\left(AO^2 - AB^2 + OB^2\right)^2}{4OB^2} - \dfrac{\left(AO^2 - AC^2 - 2x_a x_c + OC^2\right)^2}{4y_c^2}} \end{cases} \tag{7}$$

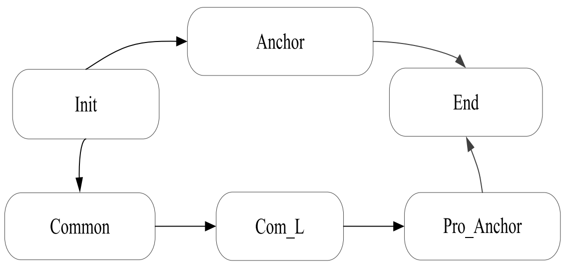


**FIGURE 3.** State conversions among nodes.

where $(x_p, y_p, z_p)$ are the coordinates of proxy anchor $p$, $(x_i, y_i, z_i)$ are the coordinates of an adjacent node $i$ of node $p$, and $d_{pi}$ indicates the measured distance from node $p$ to neighboring node $i$.

As for a common node, when its trust weight is higher than credibility $\lambda$ ($\lambda$ is figured out as the algorithm simulation test), this node will be upgraded to a proxy anchor, or it will be still used as a common.

After the trust weight of every anchor or proxy anchor is figured out, (2) is added into the weight matrix $Q$ where $Q = \text{diag}(v_1, v_2, \ldots, v_n)$. Then (10) will be obtained:

$$QAX = QB \tag{10}$$

Solving (10) with least square method will get (11):

$$X = (A^{\mathrm{T}}QA)^{-1}A^{\mathrm{T}}QB \tag{11}$$

### D. PROCESS OF 3DL POSITIONING ALGORITHM

3DL positioning algorithm can be mainly divided into three parts, namely all the nodes, anchors, and commons. The nodes have six states, including Init, Anchor, Pro_Anchor, Common, Com_L, and End. The conversions of nodal states are illustrated in Fig. 3.

The detailed execution process of the positioning algorithm is explained below:

1, All the nodes

Init: after all the nodes are scattered into a specific area, network initialization will be started. Anchors will achieve self-positioning through positioning system and will be defined as anchors before entering Anchor state. The commons will have their coordinates set to be (-1.0, -1.0, -1.0) and will be marked as commons before entering the Common state.

End state indicates the ending state of the pre-defined network positioning and the process of positioning as per the algorithm comes to an end.

2, Anchors

Anchor state: in this state, End timer will be started to execute anchor_function().

anchor_function (): anchors utilizes the network broadcast to send double-hop location package, covering *id* number of source node, type and coordinates of node, trust weight, transmitter power and gain, and broadcast hop (with default value being 2). When the End timer reaches the pre-set time, the anchors will enter End state.

3, Commons

Common state: in this state, End and Anchor_Num timers will be started to execute common_function ().

common_function (): single-hop information package is sent through network broadcast, including id number and type of node, power and gain of transmitter, and coordinates of node. com1_function will be executed when message information package is received and com2_function will be executed when location information package is received.

com1_function () utilizes can make use of RSSI ranging to figure out the distance from neighboring node and then store the data contained in message information package as well as its distance from neighboring node into the chain table of neighboring node.

com2_function () will analyze and judge the received location information package and execute com2_top2_function() when the number of broadcast hop in the package is 2 and com2_top1_funtion() when it is 1.

com2_top2_function(): with number of broadcast hop being 2, this node is a neighboring node to the broadcast source node in the information package. RSSI ranging is first used to figure out the distance from it to the anchor or proxy one, then the value and data in the package are stored into the chain table of the anchor, next the information in the chain table and its *id* number are added into the location information package, and finally the number of broadcast hop is subtracted with 1 and the information package is delivered to the neighboring node. Every time when the time interval set at Anchor_Num timer is due, it will be judged whether the total number of anchors or proxy anchors stored in the chain table of the anchor is no lower than 4. When the condition is met, weighted MLE method will be adopted to figure out the coordinates of the node and Com_L state will be activated. If the End timer reaches its preset time, the node will enter the End state.

com2_top1_funtion() means the number of broadcast hop is 1. It may exist in two situations. In one situation, the node is a node neighboring the broadcast source node of the information package, namely node $O$, $B$ or $C$ in Fig. 1. Suppose the node is $O$, the information package received by node $O$ should be from its neighboring node $B$ or $C$. Since the information package is already received by node $O$, it is discarded. In the other situation, the node is not next to the broadcast source node in the information package like node $D$ in Fig. 1. In such case, it will receive information package from its neighboring node $O$, $B$ or $C$, decide whether the double-hop node distance computation equation is satisfied and calculate the distance from this node the broadcast source node in the information package and stores it into the chain table of the anchor when it is or waits for location information package from other nodes when it is not. Every time when the time interval set at Anchor_Num timer is due, it will be judged whether the total number of anchors or proxy anchors stored in the chain table of the anchor is no lower than 4. When the condition is met, weighted MLE method will be adopted to figure out the coordinates of the node and Com_L state will be activated. If the End timer reaches its preset time, the node will enter the End state.

Com_L state: in this state, it is necessary to determine whether the node meets the condition for being upgraded to an anchor; its type will be modified to be proxy anchor and Pro_Anchor state will be executed if it is. If the End timer reaches its preset time, the node will enter the End state.

Pro_Anchor state is the state in which node is upgraded to be proxy anchor, its trust weight will be figured out, and anchor_function() will be executed.

## V. NLOS POSITIONING ALGORITHM

Unattended areas are mostly NLOS environments. Although they have no colossal obstacles as the urban buildings, they are plagued with the NLOS transmission of signals. In NLOS environments, error may be produced in node ranging under the effect of such factors as multipath and obstacle, and node positioning accuracy may be thus affected. In view of this, in this section, the WSN positioning algorithm is studied in the NLOS environments and the node positioning receives error compensation on the basis of 3DL algorithm in order to improve the positioning accuracy.

### A. ANALYSIS OF NLOS POSITIONING ALGORITHM

In present stage, some solutions have been proposed to deal with the NLOS positioning issues in WSN both at home and abroad, including Wylie identification method, sequential quadric programming (SQP) algorithm, particle swarm optimization (PSO)-based low-complexity residual weighted positioning algorithm [26]. Generally speaking, those methods mainly adopt two techniques to inhibit the effect of NLOS error, namely correcting the measured distance and reducing the weight of NLOS-affected measured distance during positioning. However, no matter which solution is chosen, the algorithm design will be quite complicated. This will significantly raise the energy consumption at node and shorten the life cycle of the network. Therefore, this paper proposes a new solution on the basis of node ranging error compensation and node positioning error compensation.

#### 1) NODE RANGING ERROR COMPENSATION

Node ranging error compensation is a kind of distance correcting method proposed for the error arising from node ranging. The main idea of the method goes like this: after WSN nodes are randomly scattered into a specific area, the anchors in the network can achieve self-positioning through the installed satellite positioning system. On this basis, the anchors can determine the distances from other anchors by means of mutual communication. In the meantime, RSSI ranging can also be employed to measure the distance between any two anchors. A comparison of the measured distance with the actual distance between two anchors will help to determine the RSSI ranging compensating error which can reduce the ranging disturbances caused by NLOS factors when being applied to the ranging between anchor and common. This will generate more accurate ranging result.

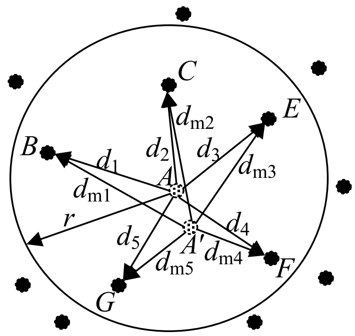


FIGURE 4. Relative positioning of anchors in 2D space.

The schematic diagram of node ranging error compensation in 2D space is shown in Fig. 4. Suppose anchor $A$ is a to-be-corrected node, $r$ is the communication radius of the node, the nodes beyond the circle are not within the communication scope of anchor $A$, the actual distances from this node to other anchors $B(x_1, y_1)$, $C(x_2, y_2)$, $E(x_3, y_3)$, $F(x_4, y_4)$ and $G(x_5, y_5)$ within the communication range are $d_1$, $d_2$, $d_3$, $d_4$, $d_5$, respectively, the RSSI-based distances from node $A$ to anchors $B$, $C$, $E$, $F$ and $G$ are $d_{m1}$, $d_{m2}$, $d_{m3}$, $d_{m4}$, and $d_{m5}$, respectively, and the MLE-corrected coordinates of node are $A\prime\,(x', y')$.

Then, the ranging correcting coefficient of anchor $A$ is expressed with (12):

$$q = \frac{1}{n}\sum_{i=1}^{n}\frac{d_i - d_{mi}}{d_{mi}} \tag{12}$$

where $n$ indicates the number of all anchors that communicate with anchor $A$. When ranging correcting parameter of the anchor is applied to the ranging computation of a common, the correcting distance $d_j$ between the common and anchor will be expressed as in (13):

$$d_j = dm(1 + q) \tag{13}$$

where $d_m$ indicates the measured distance from anchor to the common.

The node ranging error compensation in 3D space is extended on the basis of that in 2D space. Its schematic diagram is as shown in Fig. 5. Compared with 2D space, 3D space has circular communication range of anchors and three-dimensional coordinates of the nodes. The ranging correcting parameter and intra-node correcting distance can still be deducted with (12) and (13). Detailed computation is same as the node ranging error compensation process in 2D space, which is thus spared here.

#### 2) NODE POSITIONING ERROR COMPENSATION

The node ranging accuracy can be improved through the ranging error compensation method as stated above, but error remains inevitable during positioning. It is, thus, necessary

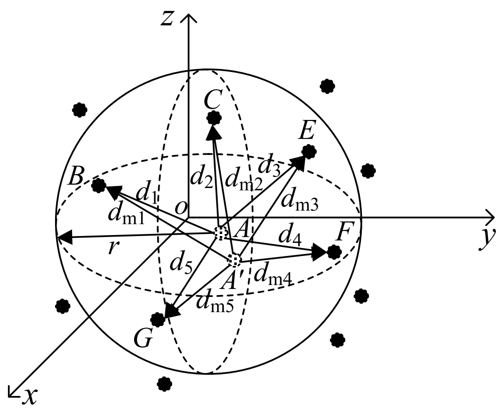


**FIGURE 5.** **Relative positioning of anchors in 3D space.**

to correct the node positioning result or perform node positioning error compensation. The principle is as follows: first, an anchor to be corrected is set, then common node coordinates solving method is employed to obtain the coordinate estimates of that anchor when there are a number of other anchors within its communication range, next the estimate is compared with the actual one, finally the positioning error of the corrected anchor within the network area is determined.

The positioning error compensation $e(e_{xj}, e_{yj}, e_{zj})$ of the to-be-corrected anchor is expressed as in (14):

$$\begin{cases} e_{xj} = x_j - x_{cj} \\ e_{yj} = y_j - y_{cj} \\ e_{zj} = z_j - z_{cj} \end{cases} \tag{14}$$

where $(x_j, y_j, z_j)$ are the actual coordinates of no. $j$ to-be-corrected anchor, are the estimated coordinates of no. $j$ to-be-corrected anchor. The final coordinates of the common can be determined as in (15) when node ranging error compensation is also taken into consideration:

$$\begin{cases} x = x_m + \sum_{j=1}^{n} \frac{1}{d_j} e_{xj} \\ y = y_m + \sum_{j=1}^{n} \frac{1}{d_j} e_{yj} \\ z = z_m + \sum_{j=1}^{n} \frac{1}{d_j} e_{zj} \end{cases} \tag{15}$$

where $(x_m, y_m, z_m)$ are the coordinates of the common resulting from 3DL positioning algorithm, $n$ indicates the total number of anchors or proxy anchors having single-hop communication with the common, and $d_j$ is the corrected distance from the common to the anchor.

### B. PROCESS OF 3DL-N POSITIONING ALGORITHM

On the basis of the 3DL positioning algorithm, node ranging error compensation and node positioning error compensation are introduced to form the 3DL-N algorithm that can achieve WSN positioning in NLOS environments. The primary pseudocodes of the algorithm are as follows:

```
Location():
Init() //network initialization//
Anchor_mutual_loc() //relative positioning of anchors
Node_send_message() //single-hop information broadcast by node
Handle_message() //nodes process the received broadcast information
While not_located_time() //execute node positioning algorithm when preset end time is not due yet
  If node_type == Anchor //anchor sends location double-hop information package
    Send_location(pkg)
  If node_type == Common //common receives and processes the information package
    pkg=Wait_location()
    If pkg.ttl==2 //execute following operations when number of hop in the information package is 2
      neighbor_node(pkg.source) //the source node of the information is its neighboring node
      Handle_location() //process location information package
      --pkg.ttl // subtract the number of hop with 1
      Send_location(pkg) //deliver the information package
      If (Anchor_num+Pro_anchor_num)>=4 //meet the node positioning condition
      Node_location
    Else if pkg.ttl == 1 //execute following steps when the number of hop in the information package is 1
      If neighbor_node (pkg.source, pkg.relay)
        Abandon_location(pkg) //discard the package when the node is similar to node O in Fig. 1
      If not_neighbor_node (pkg.source, pkg.relay)
        If two_hop_condition(pkg) //process the package when the node is similar to node D in Fig. 1
          Two_hop_ranging //carry out node ranging when double-hop ranging condition is met
        If (Anchor_num+Pro_anchor_num)>=4 //meet the node positioning condition
          Node_location
  If positioning_accuracy>=threshold //if positioning threshold is no lower than the threshold
    Up_Pro_Anchor //upgrade the common to an proxy anchor
    Send_location(pkg) //broadcast the information
```

3DL-N positioning algorithm can be mainly divided into three parts, namely all the nodes, anchors, and commons. The nodes have six states, including Init, Anchor, Pro_Anchor, Common, Com_L, and End. The conversions of nodal states are illustrated in Fig. 3, while the detailed positioning process based on algorithm is explained below.

1, All the nodes

Init: after all the nodes are scattered into a specific area, network initialization will be started. Anchors will achieve self-positioning through positioning system and will be defined as anchors before entering Anchor state. The commons will have their coordinates set to be (−1.0, −1.0, −1.0) and will be marked as commons before entering the Common state.

End indicates the ending state of the pre-defined network positioning and the process of positioning as per the algorithm comes to an end when the preset time is due.

2, Anchors

Anchor state: in this state, End timer will be strated to execute anchor_function().

anchor_function1(): anchors begin relative positioning to determine their own ranging correcting parameter and positioning error compensation before executing anchor_function2().

anchor_function(): anchors utilizes the network broadcast to send double-hop location package, covering *id* number of source node, type and coordinates of node, trust weight, transmitter power and gain, ranging correcting parameter, positioning error compensation and number of broadcast hop (with default value being 2). When the End timer reaches the pre-set time, the anchors will enter End state.

3, Commons

Common state: in this state, End and Anchor_Num timers will be started to execute common_function ().

common_function (): single-hop information package is sent through network broadcast, including *id* number and type of node, power and gain of transmitter, and coordinates of node. com1_function will be executed when message information package is received from common and com2_function will be executed when location information package is received from anchor.

com1_function () utilizes can make use of RSSI ranging to figure out the distance from neighboring node and then store the data contained in message information package as well as its distance from neighboring node into the chain table of neighboring node.

com2_function () will analyze and judge the received location information package and execute com2_top2_function() when the number of broadcast hop in the package is 2 and com2_top1_funtion() when it is 1.

com2_top2_function(): with number of broadcast hop being 2, this node is a neighboring node to the broadcast source node in the information package. RSSI ranging is first used to figure out the distance from it to the anchor or proxy one, then the information in the chain table and its id number are added into the location information package, and finally the number of broadcast hop is subtracted with 1 and the information package is delivered to the neighboring node. Every time when the time interval set at Anchor_Num timer is due, it will be judged whether the total number of anchors or proxy anchors stored in the chain table of the anchor is no lower than 4. When the condition is met, weighted MLE method will be adopted to figure out the coordinates of the node and Com_L state will be activated. If the End timer reaches its preset time, the node will enter the End state.

com2_top1_funtion() means the number of broadcast hop is 1. It may exist in two situations. In one situation, the node is a node neighboring the broadcast source node of the information package, namely node $O$, $B$ or $C$ in Fig. 1. Suppose the node is $O$, the information package received by node $O$ should be from its neighboring node $B$ or $C$. Since the information package is already received by node $O$, it is discarded. In the other situation, the node is not next to the broadcast source node in the information package like node $D$ in Fig. 1. In such case, it will receive information package from its neighboring node $O$, $B$ or $C$, decide whether the double-hop node distance computation equation is satisfied and calculate the distance from this node the broadcast source node in the information package and stores it into the chain table of the anchor when it is or waits for location information package from other nodes when it is not. Every time when the time interval set at Anchor_Num timer is due, it will be judged whether the total number of anchors or proxy anchors stored in the chain table of the anchor is no lower than 4. When the condition is met, weighted MLE method will be adopted to figure out the coordinates of the node and Com_L state will be activated. If the End timer reaches its preset time, the node will enter the End state.

Com_L state: in this state, it is necessary to determine whether the node meets the condition for being upgraded to an anchor; its type will be modified to be proxy anchor and Pro_Anchor state will be executed if it is and capability of node in delivering information package will be maintained only if it is not. If the End timer reaches its preset time, the node will enter the End state.

Pro_Anchor state is the state in which node is upgraded to be proxy anchor, its trust weight will be figured out, and pro_anchor_function() will be executed.

pro_anchor_function(): the proxy anchor sends to network broadcast double-hop location information package containing *id*number of source node, type and coordinates of the node, trust weight, transmitter power and gain, and number of broadcast hop (with default value being 2). When End timer's preset time is due, the node will enter End state.

## VI. ALGORITHM MODELING AND SIMULATION

In this section, we set to simulate the positioning algorithm proposed above and analyze the simulation result. Network modeling and algorithm simulation are conducted on OPNET and the simulation result is displayed on OriginPro.

### A. SIMULATION OF POSITIONING ALGORITHM

This section combines OPNET three-layer modeling mechanism to describe the simulation of the positioning algorithm proposed in this paper.

#### 1) NODE MODEL

The node model is demonstrated in Fig. 6.

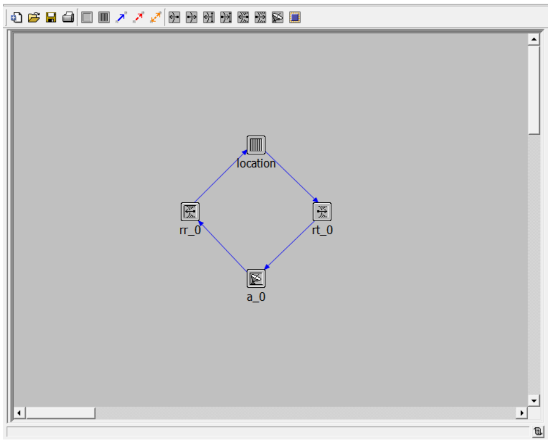


**FIGURE 6.** Simulated node model.

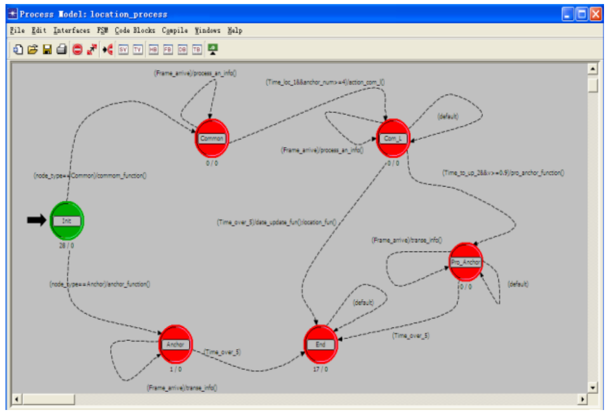

**FIGURE 7.** Schematic diagram of simulation process model.

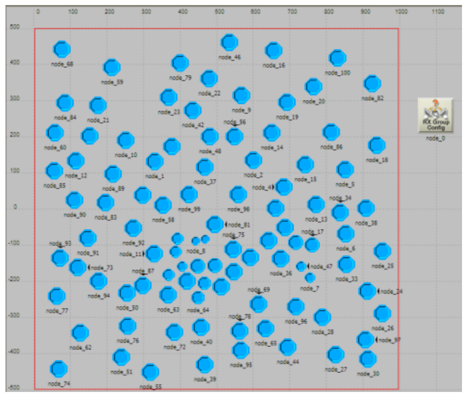

**FIGURE 8.** OPNET network model.

As shown in Fig. 6, there are four core modules in the node model and they are antenna module a_0, radio receiver module rr_0, radio transmitter module rt_0, and array module location. Among those modules, antenna module is used to send and receive data packages for the node model; receiver module acts to receive the radio signal from other node models and it is connected with the model of physical layer; transmitter module can send radio signal to other node models and it is also connected with the physical layer model as the receiver one; and array module lies at the core in the whole node model because the WSN positioning algorithm is achieved through the process model in it. The blue lines among those modules indicate the flow directions of communication data. Apart from those four modules, there are also bus transmitter module, bus receiver module, peer-to-peer transmitter module, peer-to-peer receiver module, and processor module in the tool bar, which can be selected as per practical demand.

### 2) PROCESS MODEL

Process model lies at the core of algorithm modeling simulation, in which the most important modules are the array module and processor module and their performances can be customized as per the project demand. The process model is as shown in Fig. 7.

There are six states in the process model of Fig. 7, and they are Init, Anchor, Pro_Anchor, Common, Com_L, and End. Among those states, Init indicates the process is executing some initialization work, including the coordinate initialization of anchors and commons; in Anchor state, the process is executing work concerning anchors, including relative positioning and broadcasting information packages among anchors in NLOS environments; Common state means the work concerning commons is executed, including receiving information packages from anchors, computing their own coordinates and sending information packages; Com_L state means the process is executing the positioned work of common by determining whether the node can be upgraded to be proxy node, and Pro-Anchor state will be activated when the condition is met, or the node's information package sending function will be reserved and End state will be activated after the positioning is done; Pro_Anchor indicates the process is executing the work about proxy anchors or broadcasting message to the neighboring node; End means the positioning process is done and all the nodes stop from being positioned. The conversions among different states are achieved through the transition function on the black dotted lines in the figure.

### 3) NETWORK MODEL

In this section, simulation test will be performed on 3DL positioning algorithm, 3DL-N positioning algorithm and MLE, the algorithms are compared in term of performance according to the test result. The network model hypothesized by the algorithm simulation is established with 100 WSN nodes randomly scattered in a fixed area (see Fig. 8).

In Fig. 8, what is included in the red box is a 1,000m*1,000m plane without a third dimension. This paper achieves 3D positioning by setting different 3D data in the node properties. The 100 WSN nodes within the area are numbered as 1, 2, 3, . . . , 100 in turn. Those nodes are scattered randomly in the specified area according to the randomized rapid seed configuration mechanism of OPNET and remain immobile after that, and they are provided with same system hardware and battery capacity. In those nodes, there are anchors and commons with unknown coordinates at the same time. Specific anchor density is offered in simulation. The distance among all the nodes in the network are measured through RSSI, communication radius is consistent, and the function is determined as per the type of node. Node_0 in the figure is a receiver set deployed around WSN which functions to set and uniform the communication radius, transmitter parameters, receiver parameters, and bandwidth when guaranteeing consistent communication ability of all the network nodes.

### B. DEFINITION OF INDICATORS EVALUATING THE ALGORITHM SIMULATION PERFORMANCE

In this section, we analyze and evaluate the positioning algorithm from three perspectives: positioning accuracy, network coverage and network energy consumption. Their definitions are described below:

(1) Positioning accuracy: among all the evaluation indicators for positioning algorithms, positioning accuracy directly reflects the quality of a positioning algorithm and determines whether it can be applied to the actual engineering. Positioning accuracy can be roughly divided into two types: point positioning accuracy and network positioning accuracy. The former means the coordinate accuracy of every common with positioning function achieved and it is usually to expressed as the ratio of positioning error to the single-hop maximum communication distance of single point. However, point positioning accuracy varies greatly with the type of node. This paper thus chooses network positioning accuracy as the evaluation indicator. It means the average of positioning accuracy of all nodes within the network, and its definition is as illustrated in (16).

$$\bar{e} = \frac{\sum e_i}{n} \tag{16}$$

In (16), $e_i$ indicates point positioning accuracy which can be computed as (17) while $n$ means the total number of nodes in the network.

$$e_i = \frac{\sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}}{d} \tag{17}$$

In (17), $(x_i, y_i)$ are the actual coordinates of a common, $(x_i', y_i')$ are its measured coordinates, and d indicates the maximum communication distance of the node.

(2) Positioning coverage means the ratio of anchors to total nodes in the network after WSN is done. The higher the positioning coverage is, the more effective nodes will be in the network and the better the network availability will be.

(3) Network energy consumption: the energy consumption at all the nodes in the network can directly affect the Lifecyle of the network. Therefore, on the basis of ensuring adequate positioning accuracy and coverage, the network energy consumption should be reduced as much as possible. Since node communication consumes the highest proportion of energy,

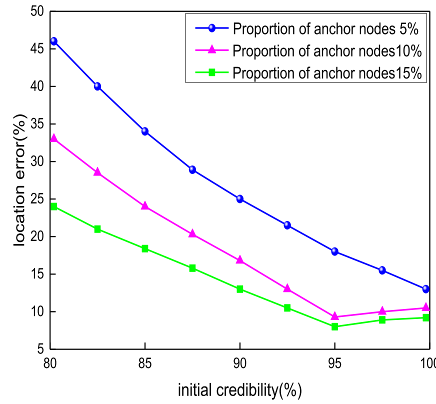


**FIGURE 9.** Relation between initial credibility and positioning error (communication radius: 300m).

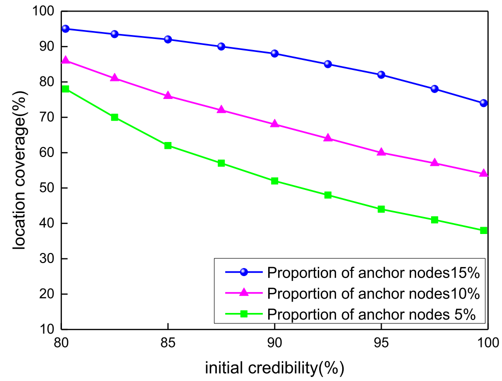


**FIGURE 10.** Relation between initial credibility and positioning coverage (communication radius: 300m).

this paper substitutes the node energy consumption with node communication volume. In simulation, network communication volume is equal to the total sum of communication volume of all the nodes.

### C. ALGORITHM SIMULATION AND ANALYSIS

Before the positioning algorithm is simulated, it is necessary to determine first the initial credibility $\lambda$ of proxy anchor. As the value affects both positioning accuracy and coverage of the algorithm, $\lambda$ is to be simulated and verified from two aspects. The simulation effect is as shown in Fig. 9 and 10.

In Fig. 9, the relation between node positioning error and initial credibility is revealed. When the anchor proportion is 5%, node positioning error simply decreases as the initial credibility rises; when it is 10% and 15%, the positioning error declines first against the rising initial credibility but slowly rises after falling to a specific value. This is because as the initial credibility rises, the positioning accuracy of the upgraded proxy anchor remains high and the number is sufficient, which reduces the positioning error of the commons. However, when the initial credibility is set to be a number approximated to 1, the number of proxy anchors available for upgrading in the network will decline dramatically and more commons demand 3DL-based double-hop ranging method to

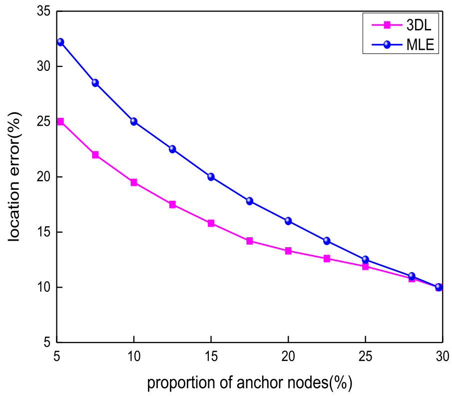


FIGURE 11. Comparison of 3DL algorithm with MLE algorithm in positioning error (communication radius: 300m).

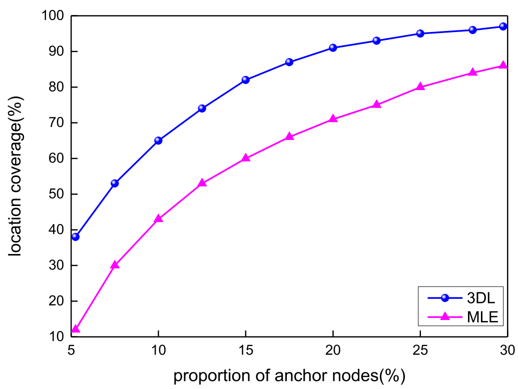


FIGURE 12. Comparison of 3DL algorithm with MLE algorithm in positioning coverage (communication radius: 300m).

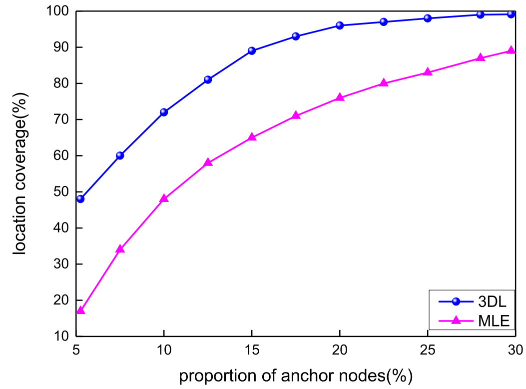


FIGURE 13. Comparison of 3DL algorithm with MLE algorithm in positioning coverage (communication radius: 400m).

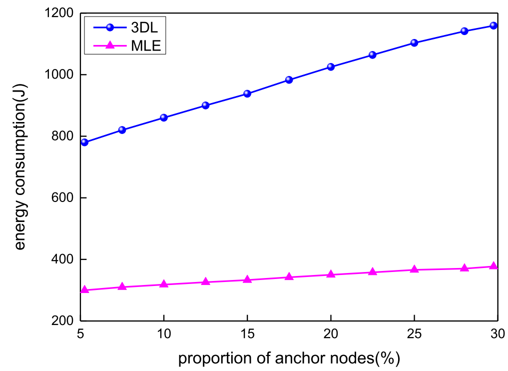


FIGURE 14. Comparison of 3DL algorithm with MLE algorithm in network energy consumption (communication radius: 300m).

estimate their distances from anchors. This further lowers the accuracy of the ranging result and then raises the positioning error.

Fig. 10 demonstrates the relation between positioning coverage and initial credibility. With higher anchor density, the positioning coverage keeps increasing. But when the anchor density is relatively high, the positioning coverage will stop from increasing further after approaching 1. This means the sparse network positioning coverage can be solved by raising the anchor density, but due attention should be paid to the factor—initial credibility. As the initial credibility is high, the number of proxy anchors available for upgrading will be reduced, so will the positioning coverage. Against low initial credibility, node positioning accuracy can be hardly assured.

In view of the analysis above, this paper sets the initial credibility for upgrading of proxy anchors to be 0.9 after considering and weighing the positioning coverage and accuracy. It means to be upgraded to be a proxy anchor, a common must have its positioning accuracy be higher than this value.

#### 1) ALGORITHM SIMULATION AND ANALYSIS OF 3DL

Because 3DL algorithm fails to consider those NLOS factors, it can be applied only to those open monitored areas. Suppose the application scenes are some unattended plains or plateaus, after regional environment is set in OPNET, positioning accuracy, positioning coverage and network energy consumption are used as indicators to simulate the feasibility and effectiveness of 3DL algorithm.

1. The positioning accuracy simulating results of 3DL algorithm and MLE algorithm are illustrated in Fig. 11.

According to Fig. 11, when anchor density remains low, 3DL positioning algorithm has a higher positioning accuracy than MLE algorithm. However, with rising anchor density, two algorithms appear to have increasingly similar accuracy. This is because when anchor density is high, 3DL algorithm turns to be an algorithm that is quite similar to MLE algorithm.

2. Since positioning coverage is affected by two factors: anchor density and node communication radius, the positioning coverages of 3DL algorithm and MLE algorithm undergo simulation verification. The simulation results are as shown in Fig. 12 and 13.

As revealed in Fig. 12 and 13, against same communication radius and anchor density, 3DL algorithm has a significantly higher positioning coverage than the MLE one. This is caused by the fact that 3DL algorithm can enlarge the coverage of anchors through double-hop ranging technique and further improve the node positioning coverage by upgrading the common to proxy anchor.

3. The network energy consumption results of 3DL algorithm and MLE algorithm are illustrated in Fig. 14.

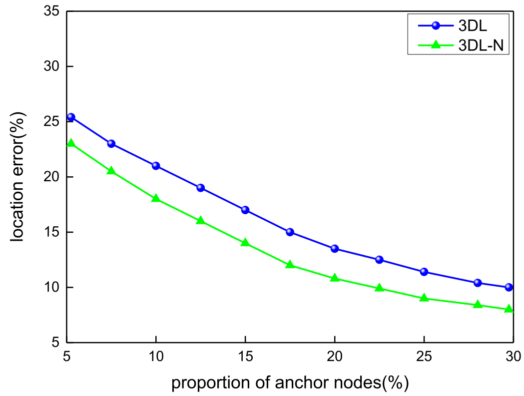


**FIGURE 15.** **Comparison of 3DL algorithm and 3DL-N algorithm in positioning error (communication radius: 300m).**

According to Fig. 14, the network energy consumption of 3DL is a lot higher than that of MLE algorithm, and the former grows more quickly than the latter. This is because no node in MLE algorithm can send any data package, but those nodes in 3DL algorithm repeatedly conduct data communication and transmit the data packages and thus consume higher network energy.

In light of the analysis above, in some open 3D environments, 3DL algorithm does achieve high positioning accuracy and coverage. A combination of network positioning cost with algorithm simulation results suggests the anchor proportion should range from 15% to 20% in order to achieve good network positioning effect in practice. Meanwhile, the simulation results also indicate this algorithm consumes high network energy, so it needs further improvement and perfection.

### 2) SIMULATION AND ANALYSIS OF 3DL-N ALGORITHM

3DL-N algorithm introduces the NLOS position technology so that its application scope is further extended. Suppose the application is carried out in some unattended areas frequently plagued by mudslide, landslide and earthquake, after regional environment is set in OPNET, positioning accuracy, positioning coverage and network energy consumption are again used to simulate and verify the feasibility and effectiveness of NLOS positioning algorithm.

1. The positioning accuracy simulation results of 3DL-N algorithm and 3DL algorithm are provided in Fig. 15.

It can be inferred from Fig. 15 that 3DL-N enjoys a higher positioning accuracy than 3DL algorithm, indicating the 3DL-N algorithm formed with 3DL algorithm as the basis and introduced with node positioning error compensation can achieve better positioning accuracy than 3DL algorithm in NLOS circumstances.

2. The positioning coverage simulation results of 3DL-N algorithm and 3DL algorithm are provided in Fig. 16.

As suggested in Fig. 16, 3DL-N and 3DL algorithms are basically same as each other in term of positioning coverage. This is because the former is improved on the basis of the latter and the improvement is limited to raising positioning accuracy instead of positioning coverage.

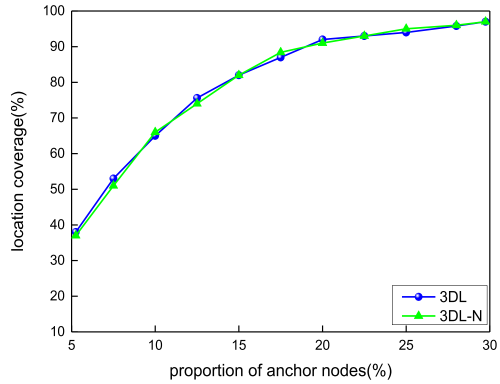


**FIGURE 16.** **Comparison of 3DL algorithm and 3DL-N algorithm in positioning coverage (communication radius: 300m).**

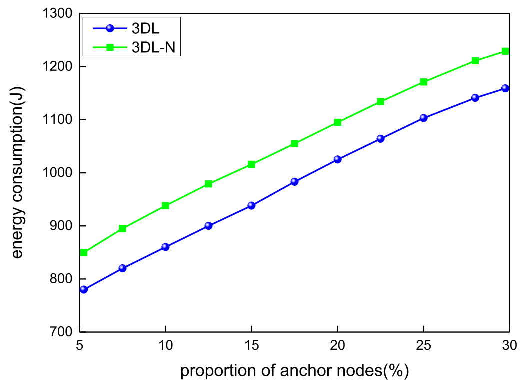


**FIGURE 17.** **Comparison of 3DL algorithm and 3DL-N algorithm in network energy consumption (communication radius: 300m).**

3. The network energy consumption simulating results of 3DL-N algorithm and 3DL algorithm are provided in Fig. 17.

According to Fig. 17, 3DL-N algorithm consumes more network energy than 3DL algorithm and the discrepancy rises with higher anchor density. This is because the node positioning error compensation adopted by 3DL-N positioning algorithm is mainly completed by anchors and higher network energy is consumed.

In view of the analysis above, in NLOS 3D environments, 3DL-N algorithm is better than 3DL one due to its higher positioning accuracy and better applicability. They don't differ much from each other in positioning coverage, but 3DL-N algorithm consumes more network energy than 3DL algorithm.

## VII. CONCLUSION

As the computer technology becomes increasingly updated, WSN gets applied more widely. It not only yields eye-catching performance in many industries such as military and national defense and medical caring but also plays a vital role in the disaster relief work in some unattended areas. It is of great social significance to keep real-time monitoring on the environmental change of some unattended areas. However, how to achieve accurate network node positioning in those monitored areas remains as a challenge to the present WSN application.

In the first place, as the unattended areas are 3D spaces, this paper concentrates on range-based positioning algorithms and introduces double-hop node ranging thought into WSN 3D positioning and then proposes the 3DL positioning algorithm. This new algorithm can realize 3D positioning of network nodes and improve the network positioning coverage by double-hop ranging of anchors and proxy anchor upgrading. Besides, anchors or proxy anchors are endowed with different trust weights in coordinate computation of commons, in the hope to reduce the effect of node error accumulation and improve the node positioning accuracy.

Secondly, since most of the unattended areas are NLOS, this paper based on 3DL algorithm introduces node ranging error compensation and node positioning error compensation to form 3DL-N positioning algorithm and meet the application requirements in unattended areas.

Finally, OPNET software is used to set the simulation environment so as to test and compare 3DL algorithm, 3DL-N algorithm and MLE algorithm. Positioning accuracy, positioning coverage and network energy consumption are used as the evaluation indicators in simulation of the algorithms. The simulation results indicate 3DL algorithm is significantly better than the MLE algorithm in terms of positioning accuracy and coverage, and its positioning accuracy is a level higher than that of 3DL algorithm. 3DL-N is more suitable for the WSN positioning in NLOS environment.

The paper also faces some limitations. Firstly, as indicated by the simulation results, 3DL algorithm and 3DL-N algorithm proposed in this paper consume higher network energy than the MLE one. This lies in further optimization of the algorithm. The sensor nodes are deployed in the way of random scattering so that some sensor nodes may lose their effect in case of locally sparse and lowly connected network when anchor proportion is low.

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