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## Coverage Hole Recovery Algorithm Based on Molecule Model in Heterogeneous WSNs

X.L. Song, Y.Z. Gong, D.H. Jin, Q.Y. Li, H.C. Jing

### Xiaoli Song\*

1. State Key Laboratory of Networking and Switching Technology,  
Beijing University of Posts and Telecommunications, Beijing 100876, China  
2. Henan University of Science and Technology, Luoyang 471023, China

\*Corresponding author: [song\\_xiaoli@163.com](mailto:song_xiaoli@163.com)

### Yunzhan Gong, Dahai Jin

State Key Laboratory of Networking and Switching Technology,  
Beijing University of Posts and Telecommunications, Beijing 100876, China

### Qiangyi Li, Hengchang Jing

Henan University of Science and Technology, Luoyang 471023, China

**Abstract:** In diverse application fields, the increasing requisitions of Wireless Sensor Networks (WSNs) have more and more research dedicated to the question of sensor nodes' deployment in recent years. For deployment of sensor nodes, some key points that should be taken into consideration are the coverage area to be monitored, energy consumed of nodes, connectivity, amount of deployed sensors and lifetime of the WSNs. This paper analyzes the wireless sensor network nodes deployment optimization problem. Wireless sensor nodes deployment determines the nodes' capability and lifetime. For node deployment in heterogeneous sensor networks based on different probability sensing models of heterogeneous nodes, the author refers to the organic small molecule model and proposes a molecule sensing model of heterogeneous nodes in this paper. DSMT is an extension of the classical theory of evidence, which can combine with any type of trust function of an independent source, mainly concentrating on combined uncertainty, high conflict, and inaccurate source of evidence. Referring to the data fusion model, the changes in the network coverage ratio after using the new sensing model and data fusion algorithm are studied. According to the research results, the nodes deployment scheme of heterogeneous sensor networks based on the organic small molecule model is proposed in this paper. The simulation model is established by MATLAB software. The simulation results show that the effectiveness of the algorithm, the network coverage, and detection efficiency of nodes are improved, the lifetime of the network is prolonged, energy consumption and the number of deployment nodes are reduced, and the scope of perceiving is expanded. As a result, the coverage hole recovery algorithm can improve the detection performance of the network in the initial deployment phase and coverage hole recovery phase.

**Keywords:** Coverage hole recovery algorithm, molecule model, data fusion, heterogeneous wireless sensor network

## 1 Introduction

The past few years have witnessed the development of wireless sensor technology and manufacturing microelectronic technology. Wireless sensor networks consist of a large number of micro sensor nodes which have perception, calculation, and communication abilities that are applied to the military or civilian areas, such as environmental monitoring, industrial control, battle-field surveillance, detection of high-risk environments, biological medicine, intelligent household, health monitoring and forecast systems [24, 25].

WSNs are composed of a large number of autonomous nodes which are densely deployed in the target region using a multi-hop, wireless communication mode, and self-organizing, large-scale high density wireless sensor network system organization. The effective deployment of nodes in a wireless sensor network is an important prerequisite for the normal operation of the WSNs [1, 16].

Underwater wireless sensor network (UWSN) is widely applied to information and data collection in many fields such as marine pollution monitoring, marine disaster prevention, underwater aided navigation, marine resources exploration, battlefield surveillance, mine detection, and underwater target detection, tracking and positioning. Thus UWSN causes intensive attention and has been one of the current research hotspots [1, 24, 25]. A large amount of research has been conducted in many applications, for example, goals locating and tracking et al, referring to UWSNs and communication protocols [15–17]. However, in view of deployment optimization research on the underwater wireless sensor nodes, the progress is still slow [9, 21, 22]. Compared with onshore wireless sensor nodes deployment, deployment researches on underwater wireless sensor nodes have more particularities, as the underwater environment is relatively complicated and the mobile wireless sensor nodes can move with water flows frequently. Therefore, it's essential to enhance the studies on how to adjust the position of the underwater wireless sensor nodes to improve the monitoring effect, according to the changeable underwater environment and considering the mobility of monitored targets [8, 12, 30].

The coverage problem is an essential problem in nodes deployment of wireless sensor network; under the condition that the residual energy and ability of perception, communication, and computing of sensor node are limited, using a certain strategy combination of software and hardware, which can ensure the coverage area, network lifetime and good connectivity, thus realize effective awareness and monitoring, is an important indicator of network perception service quality, and is also a hot topic in sensor network research [15–17, 21, 22].

In many applications, there are usually a variety of monitoring objects in the surveillant area. For example, the sensor nodes need to monitor water temperature and salinity in water environmental monitoring, or the sensor nodes need to surveil a variety of chemical diffusions to provide early warnings about factory pollution [3, 9, 10, 12, 30].

Since the hardware cost of abundant sensor nodes is higher currently, in multi-object monitoring applications, each node assembles a variety of different types of sensors; these nodes are heterogeneous. For the limitation of node energy, the more sensors are assembled on a node, the shorter lifetime of the node. Two important problems should be considered in multiple object monitoring network coverage, namely how to use less costs to obtain the ideal network coverage performance, and how to weigh the importance of network monitoring of different objects according to different objectives [8, 14, 23, 29].

Heterogeneous characteristics of heterogeneous wireless sensor networks give expression to three aspects: node heterogeneity, link heterogeneity, and network protocol heterogeneity [13, 19, 20]. Node heterogeneity includes perception ability, calculation ability, communication ability, energy, etc. The aspects of communication ability, perception ability, and residual energy have the greatest influence on the coverage. There has been little research to date on the coverage problem of the random deployment of heterogeneous wireless sensor networks.

A coverage optimization algorithm of wireless sensor network is presented to perceive the radius of the heterogeneous networks, which can effectively improve the coverage ratio in [26]. A multi-objective evolutionary algorithm based on integer vector planning is proposed in [2], which can effectively solve the problem of multiple target monitoring. Both of the two perception models which are used in [5] and [31] are relatively simple.

A routing protocol-based evolutionary algorithm is proposed for the heterogeneous cluster node of WSNs in literature [11], which can effectively reduce the errors of cluster nodes while

handling data combination and separation, and prolong the survival time of a network, but does not give the algorithm of non-cluster nodes. An efficient dynamic clustering strategy (EDCS) is put forward in literature [4], which can effectively solve the selection problem of the multi-level heterogeneous network cluster node, effectively improve the performance of a network and prolong the survival time of a network, without giving a specific node deployment algorithm, however.

A new idea is proposed by increasing heterogeneous nodes to prolong the survival of wireless sensor network in literature [18], but the heterogeneous node perception problem is not considered. To solve the sensing radius of the heterogeneous network node deployment problem, the expanding-virtual force algorithm (EX-VFA) algorithm is put forward in [28], but the connectivity and data fusion problem is barely considered in EX-VFA.

Because of the wireless sensor network nodes' energy depletion or other reasons, the area which is not covered by any node forms "empty holes" in the target field [6]. How to repair the holes is also a hot research topic [7]. To solve the problem of covering blind areas, a node deployment coverage algorithm of heterogeneous sensor networks based on organic small molecules model is proposed in this paper. Based on the organic small molecule structure model, a heterogeneous node detection model is established. In order to improve the network coverage, extend the life of the network, and achieve the optimal deployment of sensor nodes to the monitored area, a data fusion model is proposed that combines data fusion and decision rules. Randomly deployed mobile nodes will move according to the principle of the "virtual potential field." The effectiveness of the coverage algorithm is verified by simulation experiments, which can effectively reduce the number of deployment nodes and the node energy consumption, improve the efficiency of the network coverage, prolong the network lifetime, expand the detection range, and improve the detection performance of the network.

The energy consumption of the wireless sensor network determines the lifetime of the wireless sensor network directly. Reasonably deploying the wireless sensor nodes can improve the coverage effect of the wireless sensor network and reduce the movement distance of the wireless sensor nodes. A nodes deployment algorithm is designed in this article based on perceived probability model of underwater wireless sensor network within the monitored area.

The simulation results show that the algorithm in this article is superior to the virtual force algorithm on improving the coverage effect of underwater wireless sensor network and reducing the movement distance of the wireless sensor nodes, which can achieve the goal of wireless sensor network nodes' reasonable distribution to reduce energy consumption in the initial deployment phase and coverage holes recovery phase.

The rest of this paper is organized as follows:

The background literatures are introduced in Section 1. The assumption and mathematical models for node coverage and perceived are given in Section 2. The virtual force algorithm is explained in Section 3. Our algorithm in this article is presented in Section 4. The results are analyzed in Section 5. The conclusion and some future perspectives are brought in Section 6.

## 2 Related work

The sensing range of each wireless sensor node is limited in the monitored area. This requires the reasonable deployment of wireless sensor nodes according to certain algorithms in order to ensure that the entire area can be monitored within the sensing range in the monitored field.

The position of wireless sensor nodes after being randomly deployed is uncertain in the coverage problem of wireless sensor network, regarding mobile wireless sensor nodes which can't satisfy the requirements in many cases.

The mobile wireless sensor nodes move according to targets in order to improve the coverage effect of wireless sensor networks.

The movement processes consume a lot of energy, so some reasonable adjustment of the location of wireless sensor nodes and reduction of the movement distance of wireless sensor nodes thereby reduce the consumption energy of wireless sensor networks.

## 2.1 Assumption

To simplify the calculation, a quantity  $N$  of the same mobile nodes deploy randomly in the monitored region. The mobile wireless sensor node  $S_j$  owns wireless sensor network ID number  $j$ .

The same wireless sensor nodes in the network own the same sensing radius  $R_s$ , the same communication radius  $R_c$ , and  $R_c = 3R_s$ .

The wireless sensor node can obtain the location information of itself and its neighbor nodes.

The mobile node owns  $E_{ini}$  initial energy which is sufficient to support the completion of the mobile node position migration process.

The mobile node sending 1 byte data consumes  $E_s$  energy and receiving 1 byte data consumes  $E_r$  energy.

The mobile node migration of 1 meter consumes  $E_m$  energy.

The distance between the node  $S_a$  and the node  $S_b$  is  $d(S_a, S_b)$ .

The time length of the number  $k$  movement process is  $t_k$ .

The balance distance between the two wireless sensor nodes of the number  $k$  movement process is  $d_k$ .

Among them,  $d_1 < d_2 < d_3 < \dots < d_k < \dots < d_m$ .

## 2.2 Coverage model

The monitored area is  $A \times B \times C$  pixels, which means that the size of each pixel is  $\Delta x \times \Delta y \times \Delta z$ .

The perceived probability of the  $i$ -th pixel perceived by the wireless sensor network is  $P(p_i)$ , when  $P(p_i) \geq P_{th}$  ( $P_{th}$  is the minimum allowable perceived probability for the wireless sensor network), the pixels can be regarded as perceived by the wireless sensor network.

The value of  $P_{cov}(P_i)$  is used to measure whether the  $i$ -th pixel is perceived by the wireless sensor node, i.e.

$$P_{cov}(p_i) = \begin{cases} 0, & \text{if } P(p_i) < P_{th} \\ 1, & \text{if } P(p_i) \geq P_{th} \end{cases} \quad (1)$$

The coverage rate  $R_{area}$  is the ratio of the perceived area to the sum of the monitoring area, which is defined in this article, i.e.

$$R_{area} = \frac{P_{area}}{S_{area}} = \frac{\Delta x \times \Delta y \times \Delta z \times \sum_{x=1}^A \sum_{y=1}^B \sum_{z=1}^C P_{cov}(p_i)}{\Delta x \times \Delta y \times \Delta z \times A \times B \times C} \quad (2)$$

Among them,  $P_{area}$  is the perceived area while  $S_{area}$  is the sum of the monitoring area.

## 2.3 Perceived model

This article defines the event  $r_{ij}$  as the point whereby the  $i$ -th pixel  $p_i$  is perceived by the wireless sensor node with ID number  $j$ . The probability of occurrence of the event is  $P(r_{ij})$ ,

which is equal to the perceived probability  $P(p_i, s_j)$ , namely, the pixel  $p_i$  is perceived by the wireless sensor node  $s_j$ , i.e.

$$P(p_i, s_j) = \begin{cases} 1, & \text{if } d(p_i, s_j) \leq R_s - R_e \\ \ln\{1 - \frac{e-1}{2R_e}[d(p_i, s_j) - R_s - R_e]\}, & \text{if } R_s - R_e < d(p_i, s_j) < R_s + R_e \\ 0, & \text{if } d(p_i, s_j) \geq R_s + R_e \end{cases} \quad (3)$$

Where:  $d(p_i, s_j)$  is the distance between the  $i$ -th pixel  $p_i$  and the  $j$ -th wireless sensor node  $s_j$ ;  $R_s$  is the sensing radius of the  $k$ -th type wireless sensor node; and  $R_e$  is the perceived error range of the  $k$ -th type wireless sensor node.

The cooperative sensing monitoring method between lots of wireless sensor nodes is used in this research and the collaborate perceived probability of pixel  $p_i$  being perceived by any of underwater wireless sensor nodes is shown as:

$$P(p_i) = 1 - \prod_{j=1}^N [1 - P(p_i, s_j)] \quad (4)$$

### 3 Virtual force algorithm

#### 3.1 Virtual force algorithm

Assume that the wireless sensor nodes are the particulates in the electric field and that an electric force between the wireless sensor nodes exists and moves the wireless sensor nodes under the action of the electric force as evenly as possible in order to achieve a reasonable distribution of underwater wireless sensor networks, thus improving the coverage effect of the targets in the monitoring area.

If the distance between the two wireless sensor nodes is too far, the attractive force will play a major role and bring the two nodes close to each other. If the distance between the two wireless sensor nodes is too close, the repulsion force will play a major role and make the two nodes separate from each other.

Calculating the distance  $d(s_i, s_j)$  between the two nodes  $s_i$  and  $s_j$ , which determines how the mobile wireless sensor nodes should move.

The repulsion  $F(p_i, s_j)$  of wireless sensor node  $s_i$  to wireless sensor node  $s_j$  can be represented as:

$$F(s_i, s_j) = \begin{cases} \frac{k_1}{d(s_i, s_j)^{\alpha_1}}, & 0 < d(s_i, s_j) < R \\ 0, & d(s_i, s_j) \geq R \end{cases} \quad (5)$$

Where:  $k_1$ ,  $\alpha_1$  is the gain coefficient,  $d(s_i, s_j)$  is the distance between the two nodes  $s_i$  and  $s_j$ , and  $R$  is the effective distance.

The direction of the force is composed of wireless sensor node  $s_i$  to the wireless sensor node  $s_j$ . After decomposition, the component along the X-axis direction can resolve to  $F_x(s_i, s_j)$ , the component along the Y-axis direction can obtain  $F_y(s_i, s_j)$ , and the component along the Z-axis direction is found to be  $F_z(s_i, s_j)$ .

So the total value of the force along the X-axis direction is  $F_x(s_j) = \sum_{i=1}^N F_x(s_i, s_j)$ , the sum of the force along the Y-axis direction is  $F_y(s_j) = \sum_{i=1}^N F_y(p_i, s_j)$ , and the sum of the force along the

Z-axis direction is  $F_z(s_j) = \sum_{i=1}^N F_z(p_i, s_j)$ . Thus the resulting force from the circular monitoring area whose center is located in the  $k$ -th type wireless sensor nodes  $s_j$  with the radius  $R_k$  is:

$$F_{xyz}(s_j) = \sqrt{F_x^2(s_j) + F_y^2(s_j) + F_z^2(s_j)} \quad (6)$$

After force calculations according to the sum of the force, the wireless sensor node  $s_j$  moves to the new location  $(x_{new}, y_{new}, z_{new})$  from the original location  $(x_{old}, y_{old}, z_{old})$ :

$$x_{new} = \begin{cases} x_{old}, & |F_{xyz}(s_j)| \leq F_{th} \\ x_{old} + \frac{F_x(s_j)}{F_{xyz}(s_j)} \times MaxStep \times e^{-F_{xyz}^{-1}(s_j)}, & |F_{xyz}(s_j)| > F_{th} \end{cases} \quad (7)$$

$$y_{new} = \begin{cases} y_{old}, & |F_{xyz}(s_j)| \leq F_{th} \\ y_{old} + \frac{F_y(s_j)}{F_{xyz}(s_j)} \times MaxStep \times e^{-F_{xyz}^{-1}(s_j)}, & |F_{xyz}(s_j)| > F_{th} \end{cases} \quad (8)$$

$$z_{new} = \begin{cases} z_{old}, & |F_{xyz}(s_j)| \leq F_{th} \\ z_{old} + \frac{F_z(s_j)}{F_{xyz}(s_j)} \times MaxStep \times e^{-F_{xyz}^{-1}(s_j)}, & |F_{xyz}(s_j)| > F_{th} \end{cases} \quad (9)$$

Where,  $F_{th}$  is the virtual force threshold. The wireless sensor node need not move when the virtual force which the node received is less than the value. MaxStep is the maximum allowable movement distance.

The virtual force algorithm is as follows:

**Step 1:** Each wireless sensor node in the monitoring area broadcasts the information which includes the node ID and location information.

**Step 2:** The wireless sensor node updates the neighbor table information if the wireless sensor node receives the broadcast information of the neighbor nodes.

**Step 3:** Formulas (5) and (6) are used to calculate the resultant force  $F(s_j)$  of wireless sensor node  $s_j$ .

**Step 4:** Formulas (7) to (9) are used to calculate the new location where the wireless sensor nodes need to move to.

**Step 5:** The movement process won't proceed if the new location where the wireless sensor node needs to move to is located outside of the monitoring region in which case the wireless sensor node needn't move, so proceed to Step 6; otherwise it is moved to a new location, then go to Step 6.

**Step 6:** The algorithm stops when it reaches a pre-set cycle number  $T$ ; otherwise begin the next movement process, then go to Step 1.

### 3.2 Problems in the virtual force algorithm

The problem in the virtual force algorithm is the following:

Randomly deploy 16 wireless sensor nodes in the two-dimensional monitoring area and the result is shown in Figure 1 (the nodes are located in center of the circles).

According to the virtual force algorithm, all of the circles have to move to the new location; but in fact the red circles don't need to move because moving the red circles won't improve the percentage of coverage, but consumes the energy of the wireless sensor nodes.

The same problem also exists when the wireless sensor nodes are randomly deployed in three-dimensional monitoring areas.

So how to solve the problem in the nodes' density area is discussed in the next section.

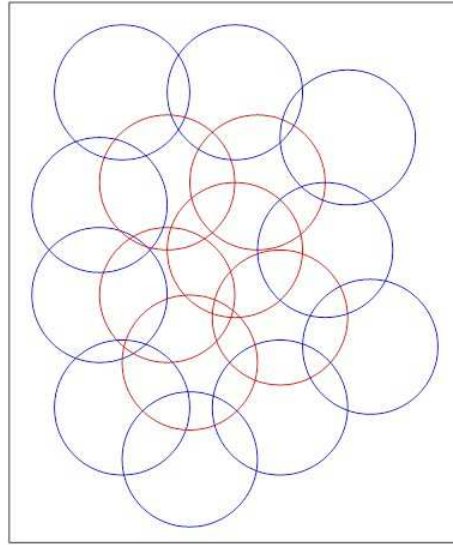


Figure 1: Sixteen randomly deployed wireless sensor nodes in the monitoring area

## 4 Perception model using molecular structure

We assume that the monitoring area  $H$  is rectangular, and that  $N$  kinds of heterogeneous perception abilities of wireless sensor nodes are randomly distributed within the rectangle  $H$ , and also assume that the wireless sensor network has the following properties:

(1) Heterogeneous perception ability sensor. Sensors have different perception abilities; the perception of the radius is different, and the node model perception is the probability perception model. The position of the sensor node  $i$  is  $(x_i, y_i)$ , the perception distance is  $r_i$ , and the perceived probability is  $p_i$  according to the function  $p_i(r_i)$ . The typical perception probability model is as follows:

$$P(S_i, Q) = \begin{cases} 0, & r + r_e \leq d_{ip}, \\ \frac{E_{ir}}{E_i} e^{(-\lambda\alpha^\beta + \alpha\delta)}, & r - r_e \leq d_{ip} \leq r + r_e, \\ 1, & r - r_e \geq d_{ip} \end{cases} \quad (10)$$

Where  $P(S_i, Q)$  is the perception probability of the sensor node  $S_i$  to target node  $Q$ ,  $d_{ip}$  is Euclidean distance between sensor node  $S_i$  and the target node  $Q$ ,  $r_e$  ( $r_e < r$ ) is an uncertainty perception measure of the sensors,  $E_i$  is the initial energy of the sensor nodes,  $E_{ir}$  is the remaining energy,  $\alpha = d_{ip} - (r - r_e)$ ,  $\lambda$  and  $\beta$  are the attenuation coefficient of perception quality for the things within the scope of sensor nodes monitoring.

$\delta$  is random number meeting normal distribution, which shows the reality of various interference in the influence of the perceived probability;

(2) All sensor nodes have the ability of data fusion, and underwater communications have enough energy to finish self-positioning and can move to the specified location freely;

(3) Before the deployment algorithm is executed, all nodes have finished self-positioning accurately, and the nodes' coordinates are known;

(4) There are three kinds of working state in node life: dormancy, detection, and communication. The node energy consumption in the communication state is the largest, and is the smallest in a dormant state. The relationship of the energy consumption and the time of the nodes in the communication state is positive. Meanwhile, the larger the communication distance, the more energy is consumed.

DSmT is put forward by the French scholar Dezert in literature [27], and is later developed jointly by Dezert and Smarandache as well as other scholars. DSmT is an extension of the classical theory of evidence, but different from basic D-S theory. DSmT can combine with any type of trust function of an independent source, but is mainly concentrated in a combined uncertainty, high conflict, and inaccurate source of evidence. Especially when the conflict between sources becomes bigger or the elements are vague or relatively imprecise, DSmT can go beyond the limitations of the D-S theoretical framework to solve complex fusion problems of static or dynamic status.

On the basis of the above assumptions and DSmT related theory, we give the following definitions:

**Definition 1:** P-reliability coverage: Assume that point  $Q$  exists in the monitoring area  $H$ , and that the credibility of the target node at point  $Q$  in sensor networks, namely, test results  $P(Q)$  meets

$$P(Q) \geq p \quad (0 < p \leq 1) \quad (11)$$

**Definition 2:** Effective coverage proportion: If the area  $H$  that needs to be monitored is two-dimensional, the acreage of  $H$  is  $S(H)$ , the acreage meeting P-reliability coverage is  $S_p(H)$ , and the ratio of  $S_p(H)$  and  $S(H)$  is

$$\eta = \frac{S_p(H)}{S(H)} \times 100\% \quad (12)$$

Where  $\eta$  is the effective coverage proportion of the two-dimensional monitoring area  $H$ .

If the monitoring area  $H$  is three-dimensional, its volume is  $V(H)$ , the volume meeting  $p$ -reliability coverage is  $V_p(H)$ , and the ratio of  $V_p(H)$  and  $V(H)$  is

$$\eta = \frac{V_p(H)}{V(H)} \times 100\% \quad (13)$$

Where  $\eta$  is the effective coverage proportion of the three-dimensional monitoring area  $H$ .

**Definition 3:** Effective detection rate: If there are  $N(H)$  target nodes in the monitoring area  $H$ , in which the  $N_A(H)$  target nodes are effectively monitored by the sensor network, then

$$\varphi = \frac{N_A(H)}{N(H)} \times 100\% \quad (14)$$

Where  $\varphi$  is the effective detection rate of the monitoring area  $H$  in the sensor network.

Organic small molecules are the organic compound whose molecular weight is under 1000, such as methane (CH<sub>4</sub>), ethane (C<sub>2</sub>H<sub>6</sub>), ethanol (C<sub>2</sub>H<sub>5</sub>OH), benzene (C<sub>6</sub>H<sub>6</sub>), etc.

The main atoms of small organic molecules are carbon atoms, hydrogen atoms, oxygen atoms, or nitrogen atoms, among others et al. They are grouped together according to certain structures as shown in Figure 2. Inspired by this, the author combined different structures' sensor nodes into one sensing unit according to certain rules. The compound nodes having different complementary sensing nodes can effectively expand the scope of perception, improve the efficiency of a single node's perception, and increase the effective coverage of sensor networks by an appropriate data fusion model.

**Definition 4:** Perception atoms: Assuming there are  $N$  sensor nodes in the monitoring area  $H$ , including  $M$  nodes which have the ability to perceive target nodes alone, the nodes that can monitor the target and transmit data to the cluster head nodes individually are called perception atoms.

**Definition 5:** Perception molecules: Assume that  $n$  kinds of sensor nodes are deployed in the monitoring area, and the different kinds of sensor nodes are combined into sensing units in



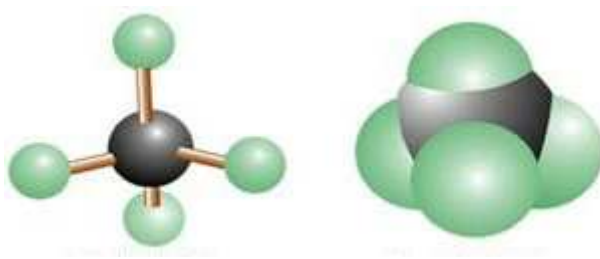


Figure 2: Structure model of methane

accordance with the appropriate data fusion model. These are called sensing unit perception molecules. Perception molecules are the smallest perception and communication unit.

Assume that there are  $n$  perception atoms in the molecule, each perception atomic data is  $\theta_1, \theta_2, \dots, \theta_n$  respectively, and then the perception molecular fusion data source is

$$U = \{\theta_1, \theta_2, \dots, \theta_n\} \quad (15)$$

Considering the perceiving unit model and data fusion model, we put forward a sensor network node deployment algorithm based on a small molecule model as follows:

**Step 1:** Build an appropriate perception model, and determine the unit (perception molecule) perception range and the position of the atom in every perception unit according to the monitoring and coverage requirements for monitoring area of  $H$ . Compute the optimal distance between the molecules, and the number of all kinds of sensing nodes.

**Step 2:** Randomly deploy sensing nodes in the monitoring area  $H$  according to the number of all kinds of sensing nodes in Step 1.

**Step 3:** Select a starting node, which usually is a node in vertex position of the monitoring area  $H$ . Then select the corresponding node closest to the starting node in order to build a sensor molecule, and set its ID to 1 consequently.

**Step 4:** Choose a perception node closest to perception molecule 1, and build the second perception molecule according to Step 3, and set its ID to 2. According to the "molecular force" principle, the force between molecules is associated with the distance between the molecules. Assume that the distance between the two perception molecules is  $D'$ , the best distance for molecules is  $D_i$ ,  $t$  is the threshold value;

When the distance  $D'$  between perception molecules meets

$$D' < D_i - t \quad (16)$$

The intermolecular force is repulsion, and node 2 moves far away from a unit.

When the distance  $D'$  between perception molecules meets

$$D' > D_i + t \quad (17)$$

The intermolecular force is attraction, and node 2 moves closely to a unit.

Until the perception molecular distance meets

$$D_i - t \leq D' \leq D_i + t \quad (18)$$

Node 2 moves completely.

**Step 5:** Using the greedy algorithm, repeat Steps 3 and 4, and adjust the molecular position until the entire molecules are adjusted.

**Step 6:** Each perception molecule completes the initialization for data fusion task allocation and data fusion node rotation sequence. Consequently, the perception molecular sensor nodes act as data fusion nodes and communication nodes in turn.

**Step 7:** The data fusion nodes collect the data of other sensors for data fusion at regular intervals.

**Step 8:** The nodes for data fusion send the data to sink nodes, and then specify a data fusion node and broadcast the messages to other nodes according to the data fusion node rotation order.

**Step 9:** Sensor nodes repeat Steps 7 and 8 after receiving the data fusion command.

## 5 Results analysis

We simulate our algorithm by MATLAB and assume that the monitoring area  $H$  is square whose side length is 3000m. The aim is to obtain  $p$ -reliability coverage in the monitoring area, and  $p = 0.9$ . The effects of target distribution and other environmental factors are not considered.

We assume that two types of sensors are used in underwater sensor networks: passive sonar sensors and giant magnetic resistance sensors. For passive sonar sensors the effective radius of perception is  $R = 50\text{m}$  under the premise of probability coverage.

According to the character of giant magneto resistance sensors and the magnetic properties of the target node, the perception range of giant magneto resistance sensors is irregular, and can be assumed to be elliptic, with an elliptical long radius  $R_a = 60\text{m}$  and short radius  $R_b = 30\text{m}$  under the condition of meeting the probability coverage. The numbers of two kinds of sensor are deployed by a ratio of 1:4 and the total number is  $N$ .

The simulation experiments are carried out using the random deployment algorithm and based on the “virtual force” deployment algorithm respectively. These two kinds of algorithm simulation results are compared with the performance of the deployment algorithm in this paper. The higher the network coverage rate and the more effective the detection rate of the target node, the better the performance of network monitoring consequently.

In the deployment phase simulate 100 times when  $N = 100, N = 120, N = 140, N = 160, N = 180, N = 200$ .

The simulation results are averaged and shown in Figures 3 to 5.

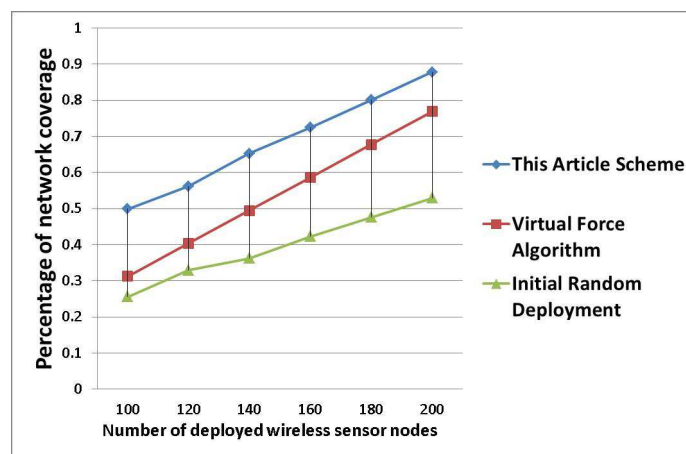


Figure 3: Percentage of coverage after deployment in different algorithms

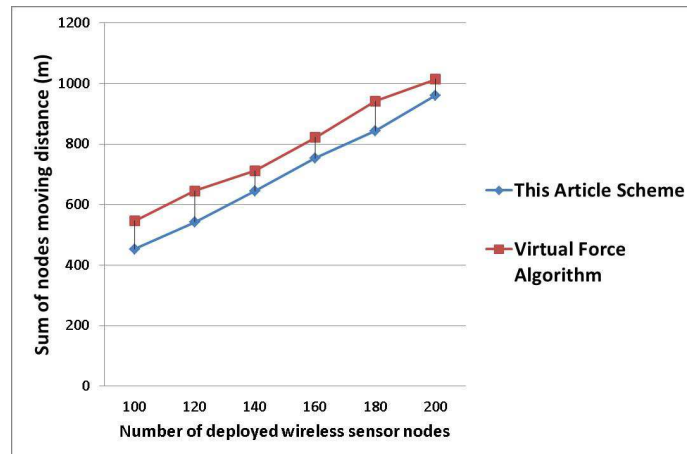


Figure 4: Sum of nodes movement distance after deployment in different algorithms

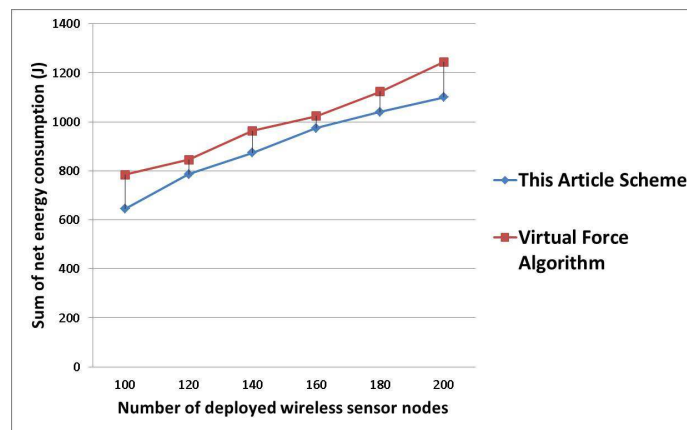


Figure 5: Sum of net energy consumption after deployment in different algorithms

Randomly lose 10 nodes after initial deployment and use their algorithms in wireless sensor networks to recover coverage holes. The results of 100 simulations are averaged and shown in Figures 6 to 8.

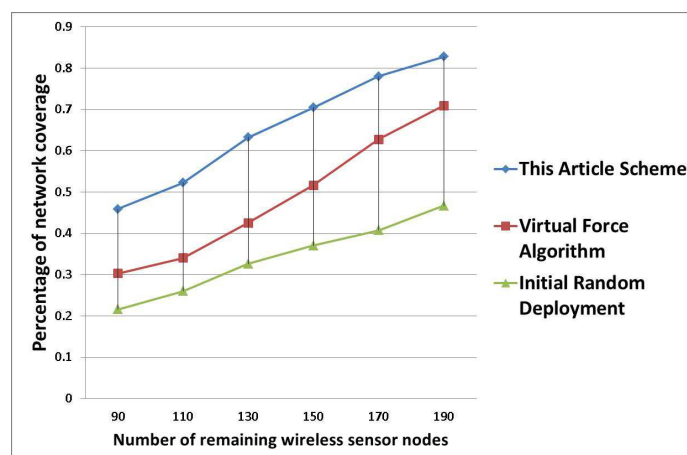


Figure 6: Percentage of network coverage after recovery coverage holes in different algorithms

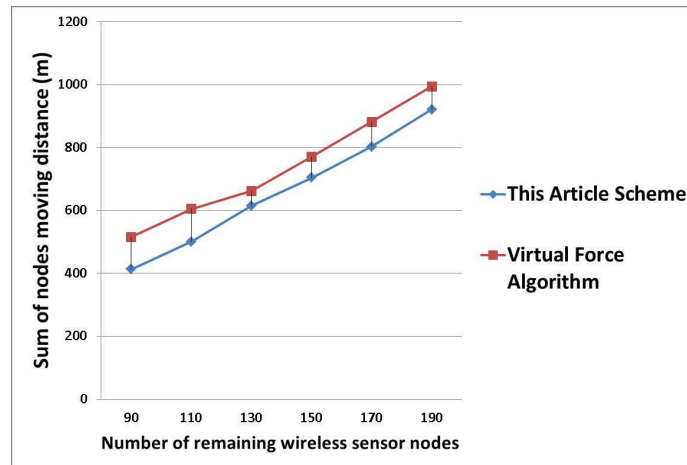


Figure 7: Sum of nodes' movement distance after recovery coverage holes in different algorithms

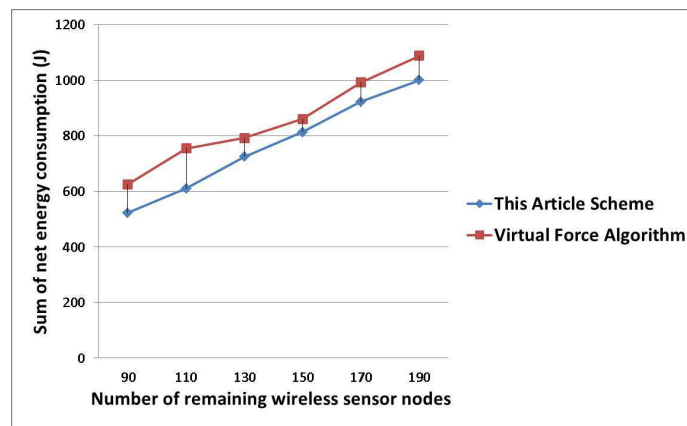


Figure 8: Sum of net energy consumption after recovery of coverage holes in different algorithms

Compared with initial nodes randomly deployed and virtual force algorithm, Figure 3 and Figure 6 show our method achieves more effective coverage rate, a single node perception is more efficient as well, which is a key target of node deployment.

The algorithm of this article reduces the blind area during perception and the scope of overlapping sense of node perception by adopting data fusion algorithm, compared with virtual force algorithm which is better than the initial randomly nodes deployed, thus obtains the best effect within the three methods mentioned above.

In our algorithm, both the number of moving perceptual nodes and the energy consumption are greater than those of the virtual force algorithm at the initial stage of deployment, nevertheless, the less energy consumption as a whole and the longer lifetime of WSN are superior to those of the rest compared methods after the complete deployment due to dormancy mechanism of redundancy node as showed in Figures 3 to 8.

The monitoring area coverage percentage increases. The sum of nodes' movement distance increases and the sum of nodes' energy consumption increases with the growing number of wireless sensor nodes as shown in Figures 3 to 8. The nodes' movement distance is larger and the coverage effect is worse when using the virtual force algorithm in areas that are dense with wireless sensor nodes, because the virtual force algorithm cannot reasonably move the wireless sensor nodes in the initial deployment phase and coverage hole recovery phase.

## 6 Conclusions

In this paper, a heterogeneous sensor network node deployment algorithm is presented based on the organic small molecule model and used to reduce the deployment node number as well as improve the efficiency of network coverage. We describe the details of our algorithm and compare it with other proposed schemes. The comparison and theory analysis show that the proposed scheme outperforms most of the existing schemes. Further work needs to be done in order to improve and optimize the model presented in this paper and try other fusion strategies to optimize the heterogeneous sensor network node deployment algorithm and make it more efficient.

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