Coverage Holes Detecting and Healing in Hybrid Wireless Networks

Chengsi Qi, Guanglin Zhang, Demin Li and Jiajie Ren
College of Information Science and Technology and Engineering Research
Center of Fashion Technology Digitized Textile Ministry of Education,
Donghua University, Shanghai, 201620, China
{chengsiqi, renjiajie}@mail.dhu.edu.cn, {glzhang, deminli}@dhu.edu.cn

1 INTRODUCTION

With the development of the network technology and extending of applied range of wireless sensor networks (WSNs), wireless sensor networks have gained widely attention for applying in natural disasters and some dangerous environment [6]. For example earthquake stricken area and old-growth forest fire. Dangerous environment exits huge security risk for the rescuers if they need enter the primary scene, but by casting a mount of sensors to the under surveillant area can not only solve the security risk problem but also make up WSNs networks to obtain the instant information of disaster area. However, because of the sensors are randomly deployed and may lead to the coverage holes, and as the data-centered network how to achieve efficient coverage is a very worthy issue to research [4].

Ghosh et al. [2] proposed the COVEN algorithm to increase the coverage, they based on the Voronoi diagram to make accurate calculation about the coverage holes. The method divided the detecting field into many cells and then divided every cell into several triangles, next discussed the relationship between sensor radius and Voronoi edge \( l_{ij} \), then worked out the uncovered area in every cell, finally dispatched the assisted sensors to heal the coverage holes. The positions of assisted nodes in COVEN algorithm must satisfy three conditions as follows:

- \( P_i \), the positions of assisted nodes must be located on the line that bisects the inner angle formed by \( V_i \), which is Voronoi vertex;
- \( P_i \) is located in the Voronoi polygon that is constructed by current sensor nodes;
- The distance between sensor node \( S_i \) and assisted node \( P_i \) is the minimum value compared with double sensing radius, \( d(S_i, P_i) = \min\{2R_s, d(S_i, V_i)\} \).

Obviously, it could increase the coverage to some extent, but it did not give the concrete algorithm about how to work out the number of assisted sensors, in addition to this, the calculation of coverage hole is relatively complicated.

Our paper resemble the paper [7] in frame. The general idea is to detect the coverage holes in every triangle, then dispatch nodes to heal the holes. What is different from previous work mainly is the simpler divide approach. In this paper, we study the area coverage of hybrid networks [7]. Assuming the initial network deployed a certain number of static nodes in the sensing field stochastically. At first, we use
static sensors to estimate the coverage holes in the random distribution sensor network, and then calculate the optimal position to deploy the assisted sensors which can heal the coverage holes. Compared with the existing methods, our approach mainly shows several advantages as follows.

- Our calculation method of coverage is simpler than other works, the simulation in section 4 shows that our approach outperform previous works by get a higher coverage ration.
- We give out the optimal position to heal the coverage hole.

The rest of the paper is organized as follows. In Section 2, the system model and problem statement is illustrated. Then, we propose the theoretical framework of the problem and our coverage algorithm in Section 3. In section 4, performance evaluation and analysis are presented. Conclusions and future work are given in the last part Section 5.

2 SYSTEM MODEL

The WSNs are consisted by many mobile sensors and static sensors, the fundamental problem in this paper is how to enhance the coverage by finding and healing coverage holes. Next, we will introduce some preparative knowledge which are used in the following analysis.

![Figure 1: Communication and sensing models](image1.png)

2.1 Communication and Sensing Model

Each sensor has communication capacity and sensing capacity, \( R_c \) is defined as communication radius and \( R_s \) is defined as sensing radius. Figure 1 shows the communication and sensing models. If and only if the distance between two sensors is within \( R_c \), they can communicate with each other, otherwise the node is isolated. Tian et al. [5] proved that \( R_c \geq 2R_s \) is the sufficient condition of tight lower bound to ensure network connectivity.

Delaunay triangulation is an important data structure in computational geometry [1]. The most significant property we use in this paper is that:

1. Maximum empty circle characteristic. The property decides the Delaunay triangulation is unique and any four points must not construct a circle.
2. Maximize the minimum angle. The characteristic means the composition of triangle is reasonable and not too narrow.

We can detect the coverage holes in each Delaunay triangle by discussing the \( R_s \) and the circumcenter \( C_0 \) of the triangle. If \( C_0 \) is not covered by the sensor node of triangle, there will exist coverage holes in the triangle. Given \( N \) static sensors \( S_1, S_2, S_3 \ldots \), we can get the Delaunay Triangulation (DT). For example, we choose 50 random nodes to construct Delaunay Triangulation in a 100 \( \times \) 100 scene by MATLAB as shown in Figure 2.

![Figure 2: Delaunay Triangulation (DT)](image2.png)

2.2 Problem Statement

The coverage of the wireless sensor network can be divided into area coverage, point coverage and barrier coverage. In this paper we mainly discuss the scheme of position selected. At first, we assume a 100\( \times \)100 scene and deploy a certain number of static sensors randomly in this area. The problem we are prepared to address is how to choose the position to deploy healing sensor nodes. To solve this issue, we need to divide the scene into small cell by Delaunay Triangulation and then discuss the position of assisted node in each cell.

To simplify the analysis of the problem later, we assume that all sensors’ sensing range is a circular with the radius of \( R_s \), and \( R_c \) is defined as communication range. In order to facilitate reading, we introduce some significant parameters as Table 1:
Table 1: main notations.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_i, M_j$</td>
<td>Static sensor and mobile sensor</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>Angle of three Delaunay triangle</td>
</tr>
<tr>
<td>$R_s, R_c$</td>
<td>Sensing radius and communication radius</td>
</tr>
<tr>
<td>$P_i$</td>
<td>Position of mobile assisted sensor</td>
</tr>
<tr>
<td>$C_0$</td>
<td>The circumcenter of the $\Delta S_1 S_2 S_3$</td>
</tr>
<tr>
<td>$\delta_{\text{uncovered}}$</td>
<td>Uncovered area of the triangle</td>
</tr>
<tr>
<td>$d(s_i, s_j)$</td>
<td>Euclidean distance between $s_i$ and $s_j$</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Input parameter to round the number of assisted sensors</td>
</tr>
</tbody>
</table>

3 COVERAGE HOLES DETECTING AND HEALING

In this section, we will elaborate the problem we have proposed above and the Heal Coverage Holes Algorithm (HCHA). The network we research is hybrid, which consists of both static and mobile sensors. During the network initialization, static sensors construct the DT.

**Step 1.** Detect if there exist the coverage holes. The approach is based on the DT which can constructed by the static sensors at the beginning.

We assume a $100m \times 100m$ scene, in the scene sensors are deployed randomly may cause the coverage holes. Helping with the DT, we can judge if there exist coverage holes or not. Nodes construct triangles as Figure 3 shows, $C_0$ is the circumcenter of the $\Delta S_1 S_2 S_3$ and the distance $d(S_i, C_0)$ is circumradius $R_s$. If $R_s > R$ then there does not exist coverage hole between the three sensors, if the $\Delta S_1 S_2 S_3$ is an acute triangle and $R_s < R$ then there must exist coverage holes between three sensors [3].

We know $C_0$ is the circumcenter of $S_i(1, 2, 3)$, according to geometry we can get conclusion easily that the distance between $C_0$ and $S_i$ is equal, so if $C_0$ is covered by sensor $S_i$, then $C_0$ must be covered by $S_i$’s neighbour nodes $S_2$ and $S_3$ as the Figure 4(b) demonstrates. It is apparently that the triangle area constructed by $S_1$ and its two neighbours do not exist coverage holes.

**Step 2.** Heal the coverage holes by finding the position of assisted nodes.

In order to heal the coverage holes efficiently, it is easy to satisfy the bow area as Figure 5 shows is minimum. We introduce two assisted angles $\alpha$, $\beta$ and $P_1$ which is the inner of $S_{\Delta P_1 R_1^1 R_2^1}$ to simpler the calculation. By mathematical theory we can get the area of $S_{\Delta P_1 R_1^1 R_2^1}$ and $S_{\text{sector} 2}$, and $S_{\text{sector} 1}$:

\[
\begin{align*}
S_{\Delta P_1 R_1^1 R_2^1} &= d \sin(\alpha) \sqrt{R_2^2 - d^2 \sin^2(\alpha)} \\
S_{\Delta P_1 R_1^2 R_2^2} &= d \sin(\beta) \sqrt{R_2^2 - d^2 \sin^2(\beta)} \\
S_{\text{sector} 1} &= \frac{R_2^2}{2} (\pi - 2 \arcsin(\frac{d \sin(\alpha)}{R_2})) \\
S_{\text{sector} 2} &= \frac{R_2^2}{2} (\pi - 2 \arcsin(\frac{d \sin(\beta)}{R_2}))
\end{align*}
\]
we can get the \( S_{\Delta 1} = S_{\text{sector}} - S_{\Delta_1} \), in a similar way \( S_{\Delta_2} \) can be calculated. Finally, the blue area is:

\[
S_{\text{blue area}} = S_{\Delta 1} + S_{\Delta 2} = \sum_{\phi=\alpha,\beta} R_1^2 + R_2^2 \left( \pi - 2 \arcsin\left( \frac{\sin \phi}{R_s} \right) \right) - 2 R_s \sin(\phi) \sqrt{R_1^2 - R_2^2}.
\]

(2)

According to the extremum theorem of the two function, easily we can get when \( \alpha = \beta \), \( S_{\text{blue area}} \) is the least, thus \( \angle S_1 P_1 S_2 = \angle S_2 P_2 S_1 \), we prove that assisted sensor should lie on the angle bisector of \( \Delta S_1 S_2 S_3 \) which is constituted by three neighbor nodes.

Pseudo-code is given in ALGORITHM 1.

4 PERFORMANCE EVALUATION AND ANALYSIS

In this section, we will conduct comparative simulations about our algorithm HCHA and COVEN, the main simulation platform we used is Matlab. In order to make a remarkable contrast, we compare HCHA deployment with the random deployment and COVEN deployment in paper [2]. The simulation area we choose is \( 100m \times 100m \) and sensing radius \( R_s \) is \( 5m \), \( \mu = 0.5 \), red nodes represent mobile sensors and blue represent static sensors.

As shown in Figure 6 the coverage ratio of HCHA deployment is higher than both random deployment and COVEN deployment. The HCHA deployment has a better performance when the number of total nodes is less than 120, and when the the number of total nodes is between 120 and 240, the HCHA still has a higher coverage ratio than both of COVEN and random deployment, as to the number of total nodes higher than 240, the coverage ratio between HCHA and COVEN hold the line.

The Figure 7 has displayed the optimal position of assisted sensor. Three blue nodes represent the static sensors and they construct the DT which is displayed by the blue triangle. To illustrate the optimal position of assisted sensors which are used to heal the coverage holes, we construct the DT with coverage holes at the beginning. The red points represent the optimal position of assisted sensors, the red circles show the healed coverage holes. The optimal position of assisted sensors should be the angle bisector of three neighbor nodes as we have proved.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we study the coverage problem in hybrid WSNs and we give HCHA algorithm based on Delaunay to estimate as well as heal coverage holes in the monitoring area, besides we solve the boundary coverage holes estimation and consider multiple assisted nodes healing deployment strategy.

For the future work, we are prepared to research the quantitative range of assisted nodes which is related to parameter.
where $k$ is the ration between $R_c$ and $R_s$. In addition, we are going to research the detail healing method by collecting the neighbour sensor nodes information.

6 ACKNOWLEDGMENT

This work was supported in part by NSF of China under Grant 61301118 and Grant 71171045, in part by the International S&T Cooperation Program of Shanghai Science and Technology Commission under Grant 15220710600, in part by the Innovation Program of Shanghai Municipal Education Commission under Grant 14YZ130, in part by the Fundamental Research Funds for the Central Universities, in part by the National Natural Science Foundation of China under Grant 61602110 and in part by the National Science Foundation for Postdoctoral Scientists of China under Grant 2016M591575.

REFERENCES


