A Probabilistic Sensor Detection Model Based on Contour Graph for Network Coverage in Wireless Sensor Networks

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Abstract—**Network Coverage is one of the most important performance metrics for wireless sensor networks (WSNs) deployment design. Higher network coverage ensures a higher quality of service (surveillance) in WSNs. In this paper, a probabilistic sensor detection model based on contour graph is proposed for network coverage evaluation. From the experiments, the optimal network coverage estimation can be performed by the proposed sensor detection models and contour graph applying.**

Keywords—**Network coverage, wireless sensor networks, probabilistic sensor detection model, contour graph**

1. INTRODUCTION

Wireless sensor networks (WSNs) have been proposed for many applications such as area surveillance, natural habitat monitoring [1]. A sensor network consists of sensor nodes that are deployed in different geographical locations within a sensor field to collectively monitor physical phenomena. The network coverage is one of the most important performance metrics to measure sensor networks. Sensor coverage models are abstraction models trying to quantify how well sensors can sense physical phenomena at some location. Network coverage, on the other hand, can be considered as a collective measure of the quality of service provided by sensor nodes at different geographical locations. There have been some researches efforts on deployment including dynamic deploying, such as virtual force (VF) algorithm, particle swarm optimization (PSO), and virtual force directed co-evolutionary particle swarm optimization (VFCPSO) [2][3][4]. But there is no discussion about deployment in the articles. We exert on coverage area estimation here. An irregular sensing field function can be represented by a simpler contour graph.

The remainder of this paper is organized as follows. We introduce about probabilistic sensor detection model and its coverage in Section 2. The contour graph of coverage for single, dual, and triple sensor node deployment are discussed in Section 3. Section 4 elaborates the estimation of coverage area. Section 5 provides some conclusions.

2. PROBABILISTIC SENSOR DETECTION MODEL

There are several types of sensor detection model in prior studies, such as binary detection model and probability detection model. Binary detection model facilitates the analysis of network; however, this model is based on unrealistic assumption of perfect coverage. To establish a more accurate detection model, probabilistic sensor detection model was proposed using environment actually state. Fig. 1 shows the scope of an omnidirectional sensor node S_i's sensing field. S_i has its detection radius r; re ($re<r$) is a measure of the uncertainty in sensor detection for r=5, re=2. The area of Range of Interested (ROI) is divided into uncertain sensing range, and certain sensing range three parts. Here, we consider the sensing detection probability as the coverage of sensor node S_i and denote as $C_P(S_i)$. In certain sensing range, $C_P(S_i)=1$ when $0\le r_d \le 3$ where r_d is the radius of index range. In uncertain sensing range, $1\ge C_P(S_i)>0$ when $3\le r_d\le 7$. In un-sensing range, $C_P(S_i)=0$ when $r_d>7$.

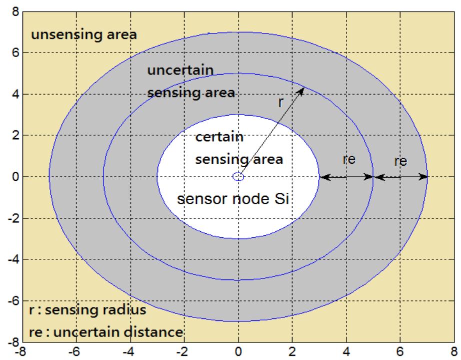

Fig. 1 An individual sensor node's sensing field.

Zou [2] proposed a probabilistic sensor detection model coverage function using an exponential sensing model, where the sensing capacity degrades according to an exponential distribution after a certain threshold, Chen [4] present an improved probability model, ensuring continuity of detection probability. The detection probability $C_P(S_i)$ of sensor S_i on point P is given as

$$C_P(S_i)=\begin{cases} 0 & if \quad d(S_i,P)\geq r+r_e \\ e^{-\lambda_1\alpha_1^{\beta_1}/\alpha_2^{\beta_2}+\lambda_2}, & if\ r+r_e>d(S_i,P)\geq r-r_e \\ 1 & if \quad d(S_i,P)<r-r_e \end{cases} \qquad (1)$$

where $d(S_i,P)$ is the Euclidean distance between S_i and P; λ_1, β_1, and β_2 are parameters measuring detection probability; $\alpha_1=re-r+d(S_i,P)$; $\alpha_2=re+r-d(S_i,P)$; λ_2 is the disturbing effect. Figure 2 shows the characteristic graph of detection probability $C_P(S_i)$ to the distance variable $d(S_i,P)$. In this example, we select a suitable curve that coverage equal 0.8 at sensing edge $d(S_i,P)=r$ when $r=5$, $re=2$, $\lambda_1=0.2$, $\beta_1=0.5$, and $\beta_2=0.5$.

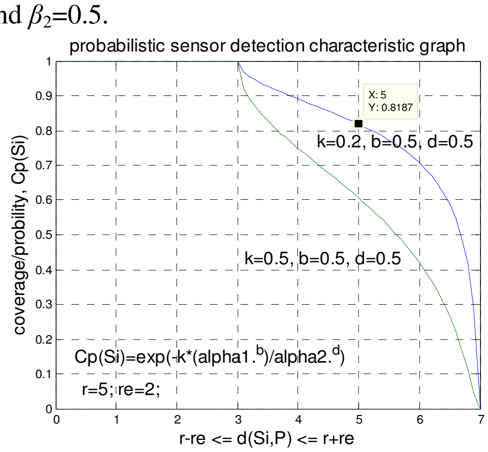

Fig. 2 Probabilistic sensor detection characteristic graph

3. Applying Contour Graph to Multiple Sensor Node Coverage

In this section, we introduce the network coverage for multiple sensor nodes field by contour graph applying. The contour graph was deemed as a sensor field. We discuss the contour graph of coverage for single, dual, and triple sensor node deployment.

3.1. Contour Graph

A contour (contour graph) for a function is a curve connecting points where the function has the same particular value [5]. In cartography, a contour joins points of equal elevation (height) above a given level. Contour lines may be either traced on a visible three-dimensional model of the surface. Fig. 3 shows that a terrain function was transferred to the contour graph.

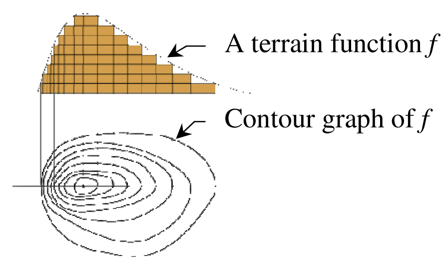

Fig. 3 A terrain function transfer to the contour graph.

3.2. Coverage of Multiple Sensor Nodes

In Section 2, the coverage function $C_P(S_i)$ expresses the magnitude of coverage at some position away from S_i. But we can't see its coverage range directly. Now, we'll sketch its contour graph to present a sensor node's scope in two dimension style. Fig. 4 is the contour graph of (1). Further on, the contour function $(1-C_P(S_i))$ is shown in Fig. 5. In Fig. 4, contour levels become larger from outer to inner (0.4, 0.7, and 1). Contract and contour levels become litter from outer to inner in Fig. 5 (1, 0.7, and 0.4). The coverage function of multiple sensor nodes is a complex function. The contour level set which represents a sensing field scope in a specific coverage value.

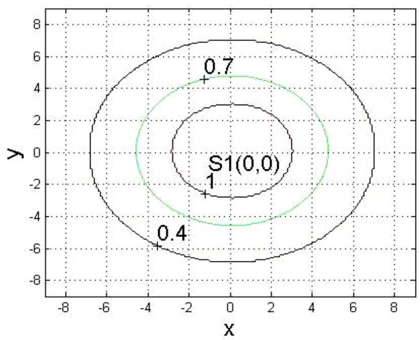

Fig. 4 Contour graph of single sensor node coverage $C_P(S_i)$

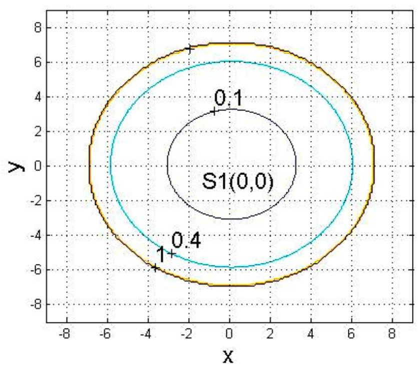

Fig. 5 Contour graph function of 1-$C_P(S_i)$

Next, consider two sensors S_i and S_j in a ROI. The term $(1- C_P(S_i))(1 - C_P(S_j))$ expresses the probability that neither S_i nor S_j covers for grid point P. Let $C_P(S_i, S_j)$ be the probability that a target at this point being detected and it is expressed as below.

$$C_P(S_i, S_j)=1 - (1- C_P(S_i))(1 - C_P(S_j)) \qquad (2)$$

Fig. 6 shows the contour graph of $C_P(S_i, S_j)$=0.9. The first case of locations of S1 and S2 with (-5, 0) and (7, 0) respectively is shown in Fig. 6(a). The second one of locations of S1 and S2 with (-5, 0) and (4.5, 0) respectively is shown in Fig. 6(b). From Fig. 6, it is shown that the coverage area in Fig. 6(b) is large than that of Fig. 6(a) because of their adjacent distance.

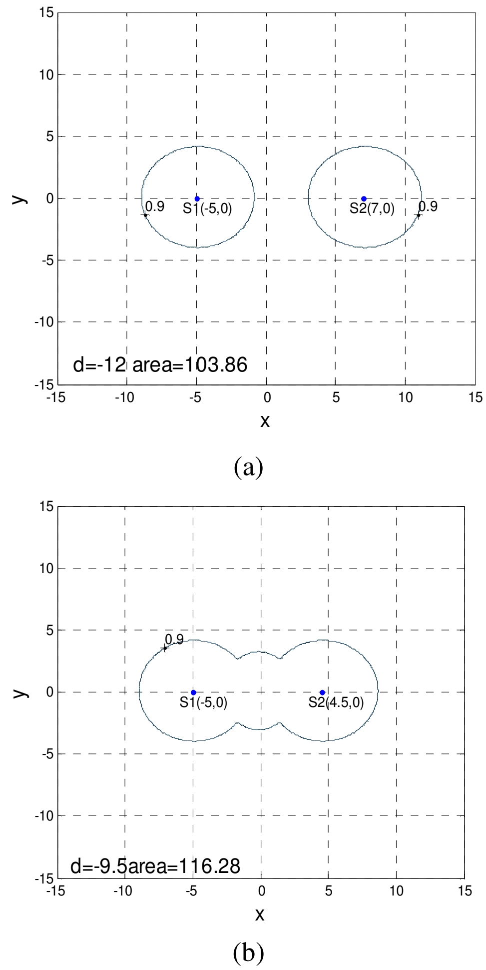

Fig. 6 Contour graph of two sensors $C_P(S_i, S_j)$

Equ. (2) can be extended to a region that consists by a set of sensors, denoted as S_{set}, $S_{set} \subseteq \{S_1, S_2, \cdots, S_k\}$. The coverage, network sensing coverage, in this case is

$$C_P(S_{set}) = 1 - \prod_{s_i \in S_{set}} (1 - C_P(S_i)) \,. \qquad (3)$$

We'll describe such statements above more detail using the examples as follows. There's three sensor nodes was deployed in a ROI (30 by 30 grids) which their sensing range and uncertainly range are r=5, re=2. They were placed in four different cases. In first case, S1, S2, S3 were placed at (-6, -6), (6, -6), (0, 6). They were separated over 10 units each other. There exists three individual sensing region as shown in Fig. 7. From Fig. 7, it is shown that the connectivity is not good at all because of their cover ranges are dividual, discontinue each other.

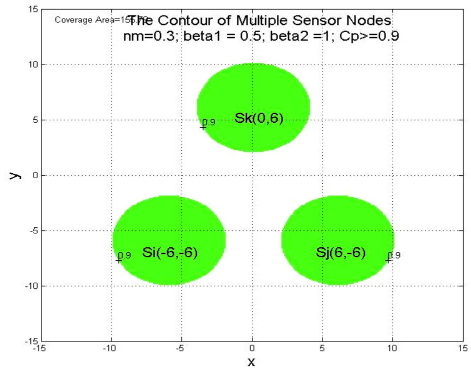

Fig. 7. Sensors deployed in case 1

In second case, S_1, S_2, and S_3 were placed at (-4.5, -3), (4.5, -3), (0, 5). They were closer each other as shown in figure 8. There's an overlap sensing region only between S_1, S_2, and S_3. The coverage and connectivity are better than first case. It means a suitable distance of adjacency is very important for multi-sensor coverage and connectivity.

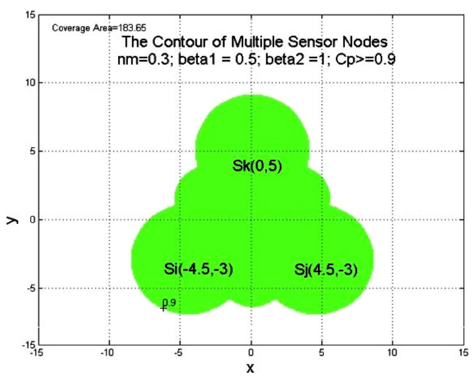

Fig. 8 Sensors deployed in case 3.

Third case, Fig. 9 shows a contour graph that includes 8 random deployment sensor nodes.

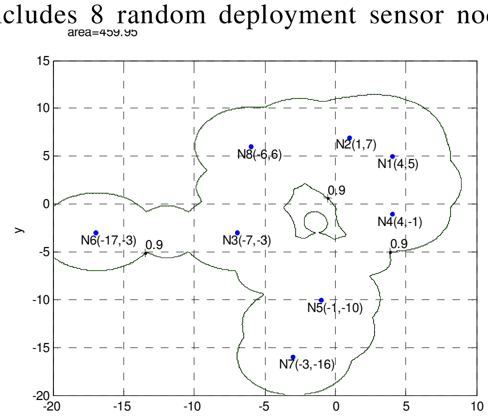

Fig. 9 A contour graph that includes 8 random deployment sensor nodes.

Fig. 10 shows a more detail contour graph from figure 9. A specific coverage various from C_p=0.9 to C_p=1 step 0.02.

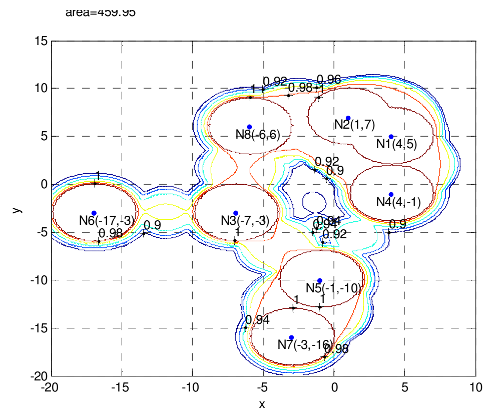

Fig. 10 A various coverage contour graph

In Fig. 10, it is shown that the higher coverage request, the smaller coverage area appearance in probabilistic sensor detection model. Therefore, we select a suit coverage not less than 0.9 for our experiments.

4. Coverage Area Evaluation

After sensing field graph had been constructed. The remaining working is coverage areas evaluation. We accomplished this job using grid-based applying. In WSNs, the sensor field is represented as a grid of points regularly. A sensor node or target in the sensor field is therefore a logical object. Multiple sensor nodes field is an irregular style. Fig. 11 shows a 10x10 grid point's field. Each grid point has its own location and represents a unit area.

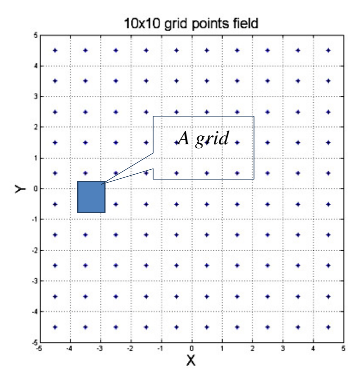

Fig. 11 A 10x10 grid points field.

By applying the example in Section 3.2, we deploy three sensor nodes in a 30x30 grid based ROI. Every grid point's coverage was evaluated. Then, total coverage function was constructed under conditional coverage greater than 0.9. Fig. 12 represents the algorithm of coverage area evaluation.

Procedure *Coverage Area evaluation* (Grid, S_1, S_2, S_3)

```
For P(x, y) in Grid, x[1, width], y[1, height]
  For Si ∈ {S1, S2, S3}
     Calculate coverage Cp(Si) for each grid
       point related with every sensor node
     Calculate Cp(Sset) for each grid point
  End
 Construct coverage function for Cp(Sset)≥Cth
End
```

Fig. 12. Coverage area evaluation algorithm.

We estimate an important threshold distance d_{th} of two sensor node that useful for their coverage area optimization as shown in Fig. 13. In Fig. 13, S1 is fixed at (0, 0) and S2 is varied from (-15, 0) to (15, 0). By applying (3), Fig. 13 shows the total coverage area for different threshold values.

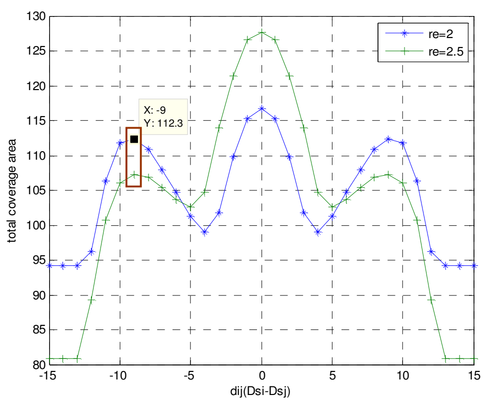

Fig. 13 The coverage area vs. threshold distance graphic of two sensor node

Table 1 describes three sensor nodes deployment, two case comparisons from location, region numbers, and total coverage areas. Case 2 is better than case 1 because of its suitable location deployment.

TABLE 1

TOTAL COVERAGE AREA COMPARISON

Case	Case1	Case2
Node Location	(-6, -6), (6, -6), (0, 6)	(-4.5, -3), (4.5, 3), (0, 5)
Region Number	3	1
Coverage Area	155.79	183.65

5. CONCLUSIONS

In this paper, we propose a coverage evaluation scheme based on probabilistic sensor detection model. Applying the contour graph, we can explicit the sensing field sketch for probabilistic sensor detection model. In our experiments, a suit coverage ≥ 0.9 is selected. How to get an optimal coverage area for sensor mobile deployment in probabilistic sensor detection model is the further work.

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