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A Coverage Strategy Based on Probability-aware Model in Wireless Sensor Networks

Huarui Wu [1,2,3,a*] and Li Zhu [1,2,3,b]

[1]*Beijing Research Center for Information Technology in Agriculture, Beijing Academy of Agriculture and Forestry Sciences , Beijing 100097, China;*
[2]*National Engineering Research Center for Information Technology in Agriculture, Beijing 100097, China;*
[3]*Key Laboratories for Information Technology in Agriculture, Beijing 100097, China*
[a]*wuhr@nercita.org.cn,* [b]*jolie.zhl@hotmail.com*

Abstract

Energy limited become a key and hot point problems of wireless sensor networks. This paper proposes a Coverage Strategy Based on probability-aware Model in Wireless Sensor Networks. The strategy using the probability-aware Model, Combining with the node coverage situation, eliminate redundant nodes, establish the optimal work node set, designed to reduce the network energy consumption, set a reasonable number of working nodes. The simulation results show that the new strategy not only to improve the network coverage, but also effectively prolong the network lifetime, improve the quality of network ,Meanwhile network coverage optimization control is realized.

Keywords: *wireless sensor networks；probability；Voronoi；Coverage Strategy；energy consumption*

1. Introduction

Wireless sensor network is composed of a large number of sensor nodes, the nodes are deployed in a certain monitoring area, which can get all kinds of information factors of monitoring environment, because the influence of the self-organization and monitoring of wireless sensor network environment, the network nodes used the battery power, in the process of network operation, node energy cannot be provided in time, which affected the entire network running performance [1-3]. How to effectively use limited energy, guarantee the data transmission, improve the network coverage, maximize the network life is an urgent problem in the wireless sensor network.

In the study of the existing network coverage, literature [4] based on node location information calculation coverage information, however, the geographical position information need dependent on the external infrastructure, greatly increased the node hardware cost and energy consumption; literature [5] can calculate covering relations between the network nodes without precise location information of nodes because there was some error calculation accuracy, leads to network part area may exist coverage blind area, makes the network monitoring information is not accurate. Liu C [6] proposed that the sensor nodes are randomly divide into k subsets, each of the sensor node subset periodically perform tasks, Because of the different application scenarios, the requirement of network coverage also are different, as long as the network monitoring area can maintain a reasonable coverage rate which can meet the application requirements, so the coverage rate can be used as one of the indicators for measure of network service quality [17]. This article designs a coverage

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algorithm based on dynamic probability-aware Model, this algorithm in the case of not affect the quality monitoring, through choosing the optimal working node set, improve the network coverage rate, reduce the network energy consumption and prolong the network lifetime. Coverage algorithm based on probability and the dynamic model considering node aware probability, combining with the Euclidean distance between the nodes and node energy information, eliminate redundant nodes, establish the optimal network working node set, prolong the lifetime of the sensor network.

2. Network Model

2.1. Probability-aware Model

Supposing N wireless sensor nodes are randomly deployed in monitoring region A, any node initial power is Q0, R0 is the node aware radius relative to the Boolean model, the Rs is the node maximum aware radius, considering the node other factors which existed in the process of perception, when the event monitoring area and node distance attenuation change occurs, the node i aware model can be represented as:

$$\Phi(P_j, R_s) = \begin{cases} 0 & R_s < d(i,j) \\ e^{-kd(i,j)^{\alpha}} & R_0 < d(i,j) \le R_s \\ 1 & d(i,j) \le R_0 \end{cases} \quad (1)$$

$\Phi(P_j, R_s)$ is the probability that point j is perceived, k and α is the attenuation coefficient, Which associated with node equipment physical properties and environmental factors. Node energy consumption rather than a linear relationship with perceived distance, node perception distance and energy consumption with the same trend change, the node perception distance and energy consumption function model can be expressed as (γ 、 β are greater than zero) :

$$Q(R_s) = \gamma R_s^{\beta} \quad (2)$$

2.2. Network Model

The WSN containing n nodes and these nodes are randomly deployed in a 2-D monitoring region A. Supposing the WSN has the following properties:

(1) wireless sensor network nodes using probability-aware model.

(2) Node communication radius R_c and the maximum perception radius meets relation: $R_c \ge 2R_S$.

(3) Node initial energy W, those node have a synchronous clock.

(4) The accurate location information of nodes in the network is known.

(5) The radius of node perception obeys normal distribution $R_i \sim N(R_0, \sigma^2)$,and the node's perception radius localized distributions within [0, 2R0].

3. Coverage Strategy Based on probability-aware Model

3.1. Related Concepts

Definition 1 （cover set）monitoring area A is divided into different Voronoi polygon area, sensor nodes set S were deployed in these areas, that is $S_i \in V_i(S, R_s, V)$, V_i is the Voronoi polygon area of S_i, Sensor node set $D \subseteq S$, if aware area of the nodes in the sensing area D can cover the area A1 completely, D is a over set of A1.

Definition 2 （cover point） Cov(i) represents that the target point i was covered, namely

$$\mathrm{Cov(i)} = \begin{cases} 1 & \Phi(\mathrm{i}) \geq \varepsilon \\ 0 & \Phi(\mathrm{i}) < \varepsilon \end{cases} \qquad (7)$$

$\Phi(\mathrm{i})$ is perceived strength of i, ε is perception threshold.

Definition 3 (network coverage rate) The ratio of covered area and monitoring area A was shown by follow:

$$\Gamma = \iint_A \mathrm{Cov(i)dA} / \|\mathrm{A}\| \qquad (8)$$

i is any point in monitoring area, $\iint_A \mathrm{Cov(i)dA}$ is the effective area of the monitoring area perceived, ‖ A‖ is the total area of monitoring area A.

Definition 4 （coverage balance degree） coverage balance degree can reduce the network energy consumption, avoid the failure of some nodes by balance work task and energy of nodes.

$$\Gamma = \sum_{i=1}^{n} \sqrt{\frac{1}{m_i} \sum_{j=1}^{m_i} [d(i,j) - \hbar_i]^2} \Big/ N \qquad (9)$$

In formula (9) Γ represents the coverage balance degree, N is the total number of the network nodes, d (i, j) is the Euclidean distance between nodes i and j, the neighbor nodes number of I is mi, $\hbar_i$ is the average of the distancesaid between node I and k , the perceive area of node k and i were overlap.

Definition 5 （coverage blind area） In the monitoring area A, if existed any point set $\Theta \subseteq A$, but Θ was not covered by node set S , Θ is coverage blind area.

Definition 6 a node set S={s1, s2…..sn} which containing N different nodes belong to 2-D region R2, The Voronoi region associated with Si,that is V(si)= {L(si, sj) i≠j},Si is a point of V(si), E is edge of (si), Vertex set V= {vi | i=1….n} is vertex set of Si Voronoi region, V (si) called Voronoi region of si in the M, If si and sj have a common Voronoi edge, and j ≠ i, si is neighbors nodes of sj. Connected line segments of neighbors constitute dual graph, G（Si, E, V） is triangulation dual graph. Figure 1 shows that a district domain node set Voronoi region, dotted line for triangulation dual graph.

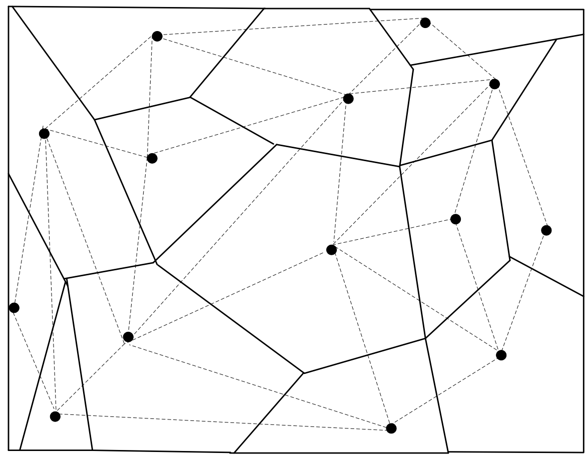

Figure 1. The Voronoi Region of wsn

Theorem 1: if nodes set S = {Si | I = 1.... N, n > t} were random deployed in the monitoring area M, when the node density reaches 80% which will need at least t nodes, region M was divided according to the node set S, So node set S must be a connected cover set of M, and S area contains all the Voronoi vertex nodes which associated with son nodes, namely any Voronoi region of node si within its scope.

Proof: area M was divided by node set S, according to definition 1, node has Voronoi region features, Si ∈ S, which were associated with any point a in V (Si) field, point a meet d (Si, a) < d (sj, a) and i≠ j, V (Si) Ξ (Si, Ri), the perceive area of Si isΞ（Si, Ri）, In light of this, ∪V(Si) ⊆M show that area M was complete coverage by S, S is a coverage set of M. On the contrary, If M was complete coverage by S, V（Si）⊆M, all points of V (si) were covered by si, and any point a in M was at least covered by a point in S.

Lemma 1: S is a coverage point set of area M, Si∈S, take a arbitrary point Sj∈S, and i ≠ j, M was divided according to Voronoi,the neighbor Voronoi region of V（sj）is Ω={∪ V（sk）k≠ j& k≠ i }.If Si was deleted from S, constitute a new set S', M was divide again, the neighbor Voronoi region of V（sj）is still Ω, S' satisfy theorem 1 , S' is a complete coverage set of M. circulation reconstruction Voronoi region for m times, until the neighbor Voronoi region Ω of V (sj) changes, So Sm is a minimum coverage set of M.

Theorem 2 when network running for T moment, if the node Si redundancy expectations E (Si) > nd, nd is network coverage rate threshold, then the node Si must be absolutely redundant node.

Prove: Suppose any point a within A was perceived by neighbor nodes, which perceived probability is P, if a node has k neighbor nodes, point a cannot be perceived which probability is （1-p）k. With the idea of independence we can see that point a was perceived by at least one neighbor node which perceived probability is 1-（1-p）k. if the area B was perceived by k nodes, and B∈A, the expectations overlapping perceived area is E (B) = 1 - (1 - P) [k] A, node Si redundancy expectations is E (B)/A = 1 - (1 - P) k. Considering the causal relationship between perceived probability and radius,so redundancy expectations and perception radius and neighbor nodes nodes were associated. When the neighbor node number exceeds a certain value, under the condition of the given coverage rate, if the redundancy node expectations outpaced threshold, Then the coverage area of the sensing node has satisfied a given coverage rate.so the nodes can be as for dormancy or closed, save network energy, it is absolutely that the node must be redundant nodes.

This paper proposed a coverage Strategy based on a dynamic probability-aware model, that is Probability dynamic Coverage Strategy (PDCS), the algorithm based on dynamic probability-aware, determine the number of the nodes in network, determined the redundant nodes minimal subset, effectively reduce the network redundancy coverage, prolong the network lifetime, strengthen the network stability, algorithm steps are as follows:

Step one: Select any node in the network si, based on probabilistic dynamic model,

probability-aware si, determine the probability of perception $\Phi(P_i, R_s)$, when $\Phi(P_i, R_s) > \Phi_0$, point will be put into the work node set Є, Φ_0 is the probability threshold, the probability for Si sensing nodes to determine their perception of the probability that when>, it will point into the work node set Є Si, where the probability threshold for the perception, in turn traversal nodes in the node set S, determine working node Є.

Step two: work node set Є as the center node, which determine any node effective perception range in node set Є, at the same time send information about themselves to its neighbor nodes, such as the radius of node, energy, perception probability , the neighbor nodes, etc., based on the relationship between the nodes Euclidean distance and perception scope $\Gamma = \min\{\sum_{i=1}^{n} f(A, d(i,j), \Phi(P_{ij}, R_s))\}$ in the node set Є, eliminate some node from Є work node set, delete the redundant nodes in work node set, which form the optimal Γ work node set, According to the relationship of network nodes, choose the reasonable number of working nodes, under the condition that the coverage rate of the monitoring area A meet the application requirements, the network energy consumption is low.

Step three: according to child nodes of the optimal node set Γ in the network distribution location , monitoring area A was divided for Voronoi polygon area, in order to establish non-overlapping Vi of Γ child nodes, i = 1, 2,....., n, and $\bigcup_{i=1,2,\ldots,n} V_i = A$, $V_i \bigcap V_j = \varnothing$.

3.3. Algorithm Correctness Analysis

Conclusion 1: n nodes are randomly deployed in monitoring region A, Node distribution density is m, time complexity of the Coverage algorithm is O (n2 logn).

When node density of monitoring region A is m, meanwhile, without affecting the network coverage rate, redundant node set that is identified depends on the basic criterion for redundant nodes, the time complexity is O(n2)；redundant nodes associated edge set was processed, which making some nodes into a dormant state, the time complexity is O(n2 logn)；loop iterates through redundant node set, the second selection dormancy node through node remaining capacity Q, the average time complexity is O(n)。Therefore, time complexity of the Coverage algorithm is O (n2 logn).

Conclusion 2 : perception area of node Si is area A , neighbors set of node Si is set G, take any point b from area A, Point b is covered by one node in G , that the coverage probability

$$P = \frac{R_0^{\ 2}}{4(R_0^{\ 2} - \sigma^2)}$$

Reference: n nodes are randomly deployed in the monitoring region A, that coverage area is Ω, the probability of the node within A is 1/Ω, take any node, such as Si, neighbors set of node Si is set G, Sj∈G, Supposing the perception radius of the node Si is Ri, Ωi is the perception region of Si ,the perception radius of the node Sj is Rj, any node within Ωi is covered by Sj, that the coverage probability P’=Rj2/(Ri+Rj)2

$$E(P')=\frac{1}{2\pi\sigma^2}\iint_D \frac{R_j^2}{(R_i+R_j)}e^{\frac{(R_i-R_0)^2+(R_j-R_0)^2}{2\sigma^2}}d_{R_i}d_{R_j}$$

$$=\frac{1}{2\pi\sigma^2}\int_0^{R_0} re^{\frac{r^2}{2\sigma^2}}dr\int_0^{2\pi}\left(\frac{R_0+r\cos\Theta}{2R_0+r\sin\Theta+r\cos\Theta}\right)^2 d\Theta \quad (1)$$

（1） was simplified shows: $E(p')=\int_{k/2}^{k}\frac{ke^{t-k}}{t}dt$ （2）

Based on the Taylor expansion: $e^t=\sum_{n=0}^{\infty}\frac{t^n}{n!}$ （3）

$k=\frac{{R_0}^2}{\sigma^2}$, According to the principle of function monotonicity

$$E(P')=\frac{{R_0}^2}{4({R_0}^2-\sigma^2)} \quad (4)$$

$$P=E(P') \quad (5)$$

conclusions can be obtained conclusions by the (4) and (5).

4. Simulation Analysis

Through simulation experiments, this paper analyzes the performance of algorithm. Experiment setting as follows: set up 120 sensor node in monitoring area, a sensor node perception radius is 5-20 m, initial capacity is 200J.In order to evaluate PDCS algorithm performance, which compare with the RCS (Random coverage strategy) algorithm of research [3] the proposed, the paper make some analysis from the following properties: (1) the number of network nodes (2) the network energy consumption (3) the network lifetime.

4.1. The Number of Network Nodes

In the process of network running, the emergence of the "failure" node will undoubtedly bring great influence to network performance, such as network connectivity, network energy consumption, network lifetime, etc. Figure 2 using the network node failure rate evaluated the network "failure" node. Network node failure rate namely the ratio of "failure" node number and the total number of nodes, it is a performance metrics which can intuitive reflect the running status of a network node. In the Figure 2, The failure nodes number of the PDCS algorithm change relatively stable in the network running late, and the node failure rate change also slower than RCS algorithm, meanwhile, the failure node total of PDCS algorithm is relatively small, further illustrates the PDCS algorithm can reduce the number of failure node, reduce network energy consumption, prolong the lifetime of node.

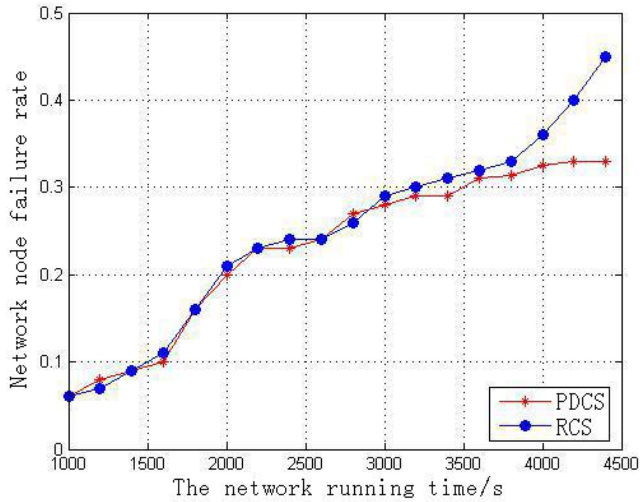

Figure 2. Failure Node Number of Algorithm

4.2. The Network Energy Consumption

Network residual energy rate is the ratio between the current moment node residual energy and initial moment energy of all nodes. The ratio refers to the network residual energy at a given time. In the network running, the node energy consumption will change at any time, as shown in figure 3, the early of network running, because running time is shorter, algorithm node coverage rate is similarity, the node residual energy ratio of two algorithms tends to approximate. However, with the change of network running time, the node residual energy ratio of two algorithms is decline, but relatively the network energy consumption of PDCS algorithm is lower than the RCS algorithm. In light of this, PDCS algorithm not only meet network coverage rate, but also can optimize network energy consumption.

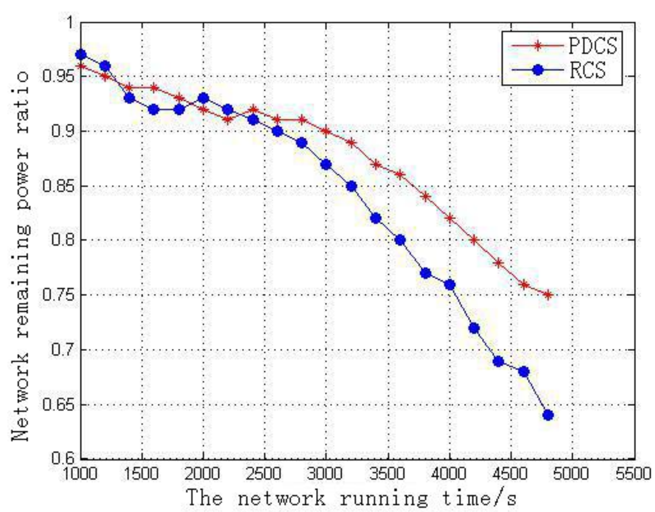

Figure 3. Network Energy Consumption of Algorithm

4.3. The Network Lifetime

Network lifetime is one of the important index to measure network performance, this paper uses the PDCS algorithm considering consider the relationship between the residual energy of nodes and the network lifetime, which make a strong link between the node residual energy and perception scope, using a value with electricity and coverage that adjust node perception range, effectively prolong the survival time of small electric nodes in the network, meanwhile, prolong the network lifetime. It can be seen from the figure 4, when the network coverage rate of PDCS is relatively close to RCS, PDCS algorithm is obviously better than the RCS algorithm on the network lifetime, especially with the time went on, this advantage is more prominent.

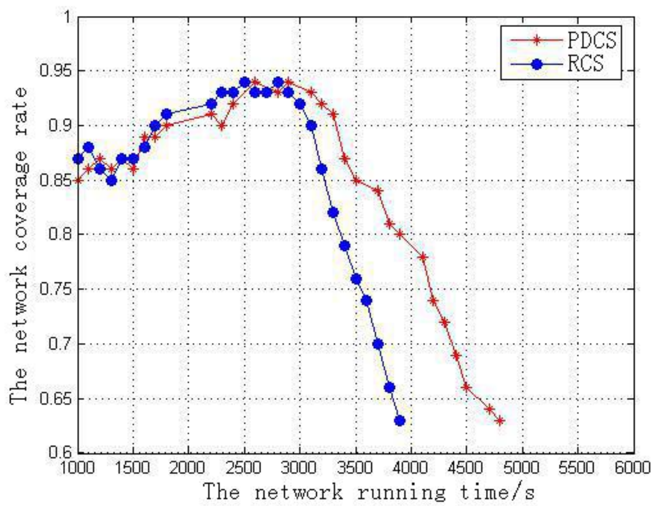

Figure 4. Network Coverage Rate of Algorithm

5. Conclusion

In wireless sensor networks, the energy balance sensor nodes and the lifetime of network are important performance factors in the network coverage control. This paper presents a coverage strategy based on probability-aware model in wireless sensor networks, according to perceived probability between network nodes, choosing appropriate working nodes set to divide the new coverage area, to improve network coverage rate, to reduce redundant nodes in the network, to decrease overall network energy consumption. Experimental results show that PDCS algorithm compared with random covering algorithm, the PDCS algorithm avoids the more redundant nodes, the number of work nodes achieved a reasonable range in the network, which reduced the network energy consumption. Meanwhile, the network performance has been improved.

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