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Coverage Optimization Strategy of Mobile Nodes in WSN Based on Nonlinear Sequence

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Abstract: Picking to meet certain condition with minimal coverage, sensor nodes to complete coverage and connectivity for wireless sensor networks has become a challenging one of core problems. For this reason, one kind based on the node mobile strategy optimal coverage algorithm was proposed. Firstly, the sensor node and the target node mapping relation model was established, which using geometric graphic in the square will target node planning to the inner square area, through to the mobile node scheduling strategy for the entire coverage area for effective coverage, achieving the goal node complete coverage of the objective. Secondly, probability expectation values were obtained through the algorithm to meet under the conditions with minimal sensor nodes, and the optimal coverage and connectivity probability models were given. Finally, the experimental results show that the algorithm can not only using the least nodes to complete the effective target area to be covered, but in reducing the network energy consumption has also greatly improved, simultaneously reducing the cyber source configuration and improving the network life cycle. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor networks, Coverage optimization, Connectivity, Mobile nodes, Nonlinear sequence.

1. Introduction

Wireless Sensor Network (WSN) is a network system formed by a large number of inexpensive self-organizing sensor nodes with these features: computing power, perception, communication capabilities, which is widely used in a variety of scientific fields such as defense monitoring, environmental monitoring, mine rescuing, medical and transport. Coverage and connectivity has become one of the basic problems of wireless sensor networks research [1-3]. Reasonable and effective coverage in wireless sensor network coverage application process helps to increase the effective suppression of the network nodes energy, improve the perceived quality of service and extend the overall network lifetime. It also increases the cost of network-related data transmission, information management, data storage and calculation. Under the premise of meeting certain coverage and connectivity rate ratio, the network lifetime has become a very crucial topic.

Therefore, how to fulfill the coverage and connection of designated regions and suppress the excessive energy consumption of sensor nodes at the least sensor nodes under the condition of certain coverage is a challenge. Based on the above ideas, three issues should be solved: first, planning the monitored target node to a square region, the association model between the sensor node and destination node is established to place the target node within the range of the sensor nodes. Secondly, by using of the mobile node scheduling strategy and parameters dynamically change, coverage region of mobile node is reduced, which achieves effective coverage of the target region, and enhance the network topology. By calculating and reasoning of the side length of covering region, the number of nodes required under the different rates of coverage and connectivity.

In recent years, many domestic and foreign experts and scholars put forward many theories and solutions on the coverage of wireless sensor networks and connectivity issues [4-6]. In addition, with the increase of the sensor nodes and coverage region changes, the complexity of the algorithm will become larger, and thus computational efficiency will reduces [7-8]. The coverage configuration protocol (CCP) proposed by reference [9] is to judge the distributive node functions qualification using the local node location information, which is when the communication radius is greater than or equal to 2 times the sensing radius and the network k-cover the given convex region in the region, the network is k-connected, thereby promoting its agreement to meet the multi-coverage requirements. LEACH protocol has been improved in reference [10]. The main idea is: clustering routing algorithm uses periodic random selection of cluster head node to balance the node energy consumption and to achieve the purpose to extend the network lifetime.

Under the premise of maintaining a certain coverage and connectivity rate, in the operation of each data retrieval collected by the sensor nodes, a subset of a sensor node is selected to collect data and to realize nodes subsets dynamic scheduling conversion mechanism, and thus achieve the optimal choice for each subset of data acquisition, thereby optimizing the number of nodes, improving network stability and extending the lifetime of wireless sensor networks. Finally, the number relations of nodes needed to be deployed in coverage and connectivity is given under the condition whether there is influence of edge node.

2. Definition and Network Model

2.1. Assumption and Definition

The coverage and connectivity this paper studies is based on local positioning algorithm and has the following basic assumptions:

Assumption 1: The covering radius and communication radius of each node showed a disc-shaped.

Assumption 2: the specific location information of its own node is obtained through some localization algorithm, such as: the RSSI location algorithm, the Euclidean positioning algorithm, without the participation of large-scale physical communications equipment.

Assumption 3: All sensor nodes are randomly and uniformly deployed in square in side length l monitoring region Ω with consideration of the boundary of deployment region.

Assumption 4: The perception of each node is much smaller than the entire network coverage region, and all nodes are isomorphic and initial energies are equal.

Definition 1: Set up a two-dimensional plane E, the coordinates of the nodes s_i (x_i, y_i), the coordinates of the target t_k (x_k, y_k), the Euler distance between the nodes s_i and t_k is less than s_i, perception radius r_s: that is $ES_i = \left\{ t_k \left| t_k \in E^2, D\left(s_i, t_k\right) \le r_s \right. \right\}$, said point t_k is covered by s_i.

Definition 2: for a given target set $T=\{t_1,t_2,t_3\cdots t_k\}$ and the sensor node set $V=\{v_1,v_2,v_3\cdots v_n\}$, in a time slot, if the target set T in any goal t_k is covered by at least one node within node set V, then the target set T is full coverage.

Definition 3: suppose that nodes s_i, s_j, the target regions they cover are C_i and C_j, and $C_i \cap C_j \ne \varnothing$, so nodes s_i and s_j are coverage connected. Suppose that T is an m nodes set randomly distributed in the target region, E is the set of edges of the network figure, indicating that the e_{ij} = 1 positional relationship in e_{ij}; e_{ij} represents the positional relationship of node s_i and the target node t_j. When e_i = 1 when and only when the Euclidean distance of target node t_j and the node s_i is less than or equal to the perception radius r_i, otherwise e_i = 0. $W = \{w_1, w_2 \cdots w_n\}$ is the initial energy set of sensor nodes; W is in normal distribution; the w_i represents initial energy of sensor node s_i; w_i is the maximum energy in the process of node work.

Definition 4: In the monitoring region any point at least at the same time located in the perception range of K nodes is known as the K re-cover. That is $A_k \in \bigcap_{i=c}^{c+k} As_i$, where $1 \le c \le n$.

Definition 5: coverage rate of a point s_i in coverage region is as follows:

$$p\left(s_i, s_j\right) = \begin{cases} 0 & \text{if } R_s \le d\left(s_i, s_j\right) \\ e^{-\varepsilon d} & \text{if } \left(R_s - R_e\right) < d\left(s_i, s_j\right) < R_s \\ 1 & \text{if } d\left(s_i, s_j\right) \le \left(R_s - R_e\right) \end{cases} \quad (1)$$

which $d = d\left(s_i, s_j\right) - \left(R_s - R_{\mathrm{e}}\right)$, ε is physical parameters of the sensor node; R_{e} represents the monitoring dynamic parameters of the sensor nodes; $d\left(s_i, s_j\right)$ represents the Euclidean distance between the sensor nodes s_i, s_j; When the coverage $p(s_i, s_j)$ of a node s_i meets $d(s_i, s_j) \le (R_s - R_e)$, then the node is detected, otherwise not [11].

2.2. Parameter Establishment and Variable Description

l: side length of the square coverage region;
Ω: the network region, i.e. $\Omega=l^2$;
n: number of randomly deployed network nodes;
r_s: the sensing radius of sensor nodes, $r_s<l$;
r_t: the communication radius of sensor nodes, $r_t<l$;
E(C): The expectations of sensor node coverage ;
$P(S_n)$: a network expect coverage rate of *n* randomly deployed nodes;
$P(C_n)$: network connectivity probability of *n* randomly deployed nodes.

2.3. Network Model

Usually, coverage directly reflects the extent that the objectives are concerned, the concerned target node region having higher coverage, taking into account the functional relationship between sensor node *p* in the region II expectations and coverage region, shown in Fig. 1.

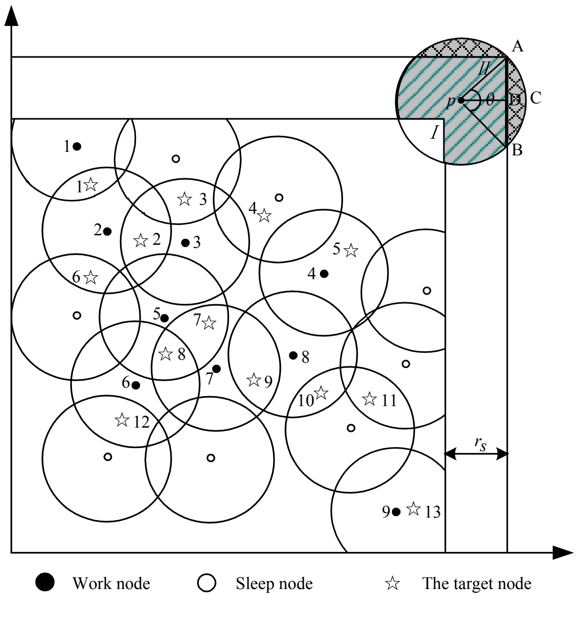

Fig. 1. Diagram of connective coverage of target region and node p in II region.

Fig. 1 shows the relation model of working sensor node, dormant node and target node. The black sensor nodes are in working state, and the rest are in a dormant state. Relation the information obtained by perception of the target node.

3. Network Properties Calculation and the Algorithm Description

Now take the analysis of Fig. 1 as the example. The square region l is divided into I and II two parts. Randomly deploy the nodes in the monitoring region to construct a finite set *S* with the coverage region of each node being *E(C)*, so that the coverage probability of each node is *E(C)/Ω*. When the nodes set is empty, the network coverage of the n deployed nodes will be $P(S)=(1-E(C)/\Omega)^n$ Thus the network nodes probability value has been obtained in the situation that collective S is not an empty set.

$$P(S) = 1 - (1 - E(C)/\Omega)^n \tag{2}$$

When a node is in the area between I and II, the boundary coverage of the network coverage area can be shown in Fig. 2.

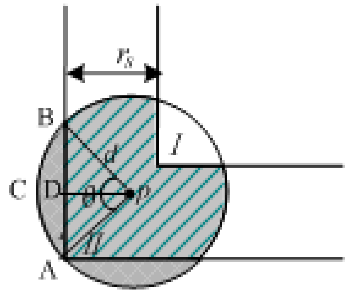

Fig. 2. The boundary coverage of the network coverage area.

When the number of nodes $n \to \infty$, $\lim_{n\to\infty} E(P(S)) = 1$, which indicates that the number of nodes is large enough, this coverage region is completely covered [12]. Considering the boundary effect in solving the node coverage region and expectations, because the square region is divided into region I and II, based on the concept of expectation value in probability, expectation value of the coverage of network nodes can be obtained:

$$E(C) = P(\Omega_I)E(C_{\Omega_I}) + P(\Omega_{II})E(C_{\Omega_{II}}) \tag{3}$$

Among them, $P(\Omega_I)$ and $P(\Omega_{II})$, respectively represents the probability values of the randomly deployed nodes in region I and II. $E(C_{\Omega_I})$ and $E(C_{\Omega_{II}})$ denotes the corresponding expectations of coverage. From the even distribution functions of the random deployment of sensor nodes, then get:

$$\begin{aligned} P(\Omega_I) &= (l - r_s)^2 / l^2 \\ P(\Omega_{II}) &= 2r_s(l - r_s)/l^2 \end{aligned} \tag{4}$$

Assume that node p is in the region I, its coverage being completely contained, so the coverage expectation is:

$$E(C_{\Omega_I}) = \pi r_s^2 \tag{5}$$

When a node p is in region II, the region should equal to its sensing region of the circumference subtracting bow region S_{ACBD}. A and B is the intersection of the sensing circle of node p and network boundaries, whose angle θ is the central angle formed by the node p and A, B, $\angle ApB=\theta$, $\theta = 2\arccos y/r_s$ so:

$$\begin{aligned} E(C_{\Omega_{II}}) &= 2\int_0^{l-r_s} \frac{1}{2} r_s^2 (2\pi - \theta + \sin\theta) dx \int_0^{r_s} \frac{1}{2(l-r_s)r_s} dy \\ &= \frac{r_s}{2(l-r_s)} \int_0^{l-r_s} (2\pi - \theta + \sin\theta) dx \int_0^{r_s} dy \end{aligned} \tag{6}$$

Theorem 1: Suppose that the n sensor nodes randomly deployed in the network region with an area of Ω, the node perception radius r_s, in an area of πr_s^2 region, probability of K nodes is: $\left(N\pi r_s^2\right)^k e^{-\frac{N\pi r_s^2}{\Omega}} \Big/ \Omega^k K!$

Proof: By Poisson's theorem, when the number of sensor nodes N tends to positive infinity, the probability P tends to infinitesimal, and its quadratic distribution item $B(n,p)$ can be approximated as Poisson distribution $p(n,\lambda)$, $\lambda = np$, within the coverage region the sensor nodes are randomly deployed, so the number of nodes in the network area of πr_s^2 can be seen to obey the quadratic distribution $B\left(n, \frac{\pi r_s^2}{\Omega}\right)$. Because sensors are deployed in high density in coverage region and the perception radius of each sensor node is much smaller than network area Ω, when the number of sensor nodes n in the coverage region increases, $n\pi r_s^2/\Omega$ gradually approaches infinitesimal, and then the quadratic distribution can be approximated as the Poisson distribution $p(n, n\pi r_s^2/\Omega)$, that is the probability of network coverage rate at K at any point of the region is $P = \frac{\lambda^k}{k!} e^{-\lambda}, K \in N$.

Theorem 2: Suppose the given sensing radius of r_s nodes are evenly distributed in the square of side length l, considering the boundary factors, the node coverage expectations will be:

$$E(C) = \left(\frac{r_s}{l}\right)^2 [\pi(l-2r_s)^2 + 2(l-r_s)\left(2\pi r_s + \frac{\pi}{2} + r_s\right)] \tag{7}$$

Proof: because the sensor nodes obey even distribution function, the coverage expectations can be obtained by the formula (2): $E(C) = P(\Omega_I)E(C_{\Omega_I}) + P(\Omega_{II})E(C_{\Omega_{II}})$, substitute formulas (3), (4), (5) into formula (2):

$$\begin{aligned} E(C) &= P(\Omega_I)E\left(C_{\Omega_I}\right) + P(\Omega_{II})E\left(C_{\Omega_{II}}\right) = \\ &\frac{1}{l^2}[\pi r_s^2 (l-2r_s)^2] + \frac{1}{l^2}[2r_s^2 \int_0^{l-r_s} (2\pi - \theta + \sin\theta) dx \int_0^{r_s} dy] \\ &= \left(\frac{r_s}{l}\right)^2 [\pi(l-2r_s)^2 + 2(l-r_s)\left(2\pi r_s + \frac{\pi}{2} + r_s\right)] \end{aligned} \tag{8}$$

Definition 6: If the mobile node locates in x_i, the repulsive force of any other node j located in x_j is defined as:

$$F_{exc} = \begin{cases} k\left(\frac{1}{r_s} - \frac{1}{d(i,j)}\right)\left(\frac{x_i - x_j}{d(i,j)^2}\right) & d(i,j) \le r_s \\ 0 & d(i,j) > r_s \end{cases} \tag{9}$$

Similarly: the attractiveness of the node j on i is defined as

$$F_{att} = \begin{cases} k\frac{1}{d(i,j)^2}\left(\frac{x_i - x_j}{d(i,j)}\right) & d(i,j) > 2r_s \\ 0 & d(i,j) \le 2r_s \end{cases} \tag{10}$$

where k proportionality constant coefficients, the repulsive and attractive is respectively:

$$\begin{cases} F_{exc} = \sum_{j\in\Omega} F_c(i,j) \\ F_{att} = \sum_{j\in\Omega} F_c(i,j) \end{cases} \tag{11}$$

4. Performance Assessment

To further verify the effectiveness of the algorithm, the curves between coverage rate and node, as well as curves between connectivity rate and nodes under different network size are selected, as shown in Fig. 3.

Fig. 3 shows the number chart of sensor nodes needed to deploy to realize different network connectivity under different network size. With the expansion of the network size, to realize certain network connectivity rate, the number of nodes needed to be deployed will also increase. When connectivity rate is high, the number of nodes needed to deploy increases faster.

Consider coverage and connectivity rate influenced by the boundaries. Fig. 3 shows the number of sensor nodes required to be deployed under the conditions without boundary effects with the same network size *l*=300 *m* coverage and connectivity rate. With the increase of network coverage and connectivity, the number of nodes required increases substantially; and the influences gradually become smaller and in equilibrium at last when the network coverage and connectivity rate increases.

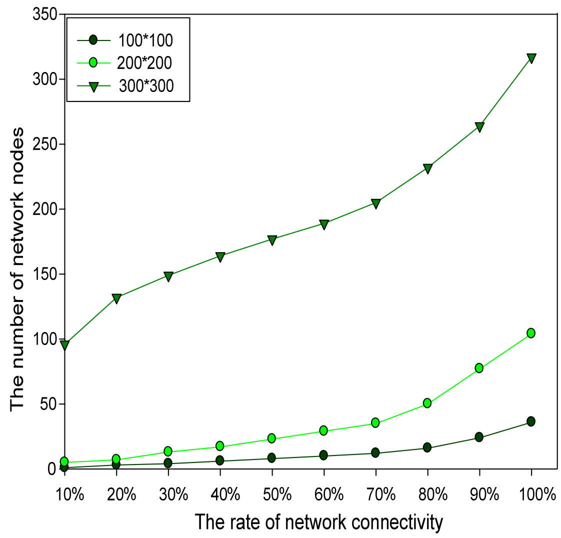

Fig. 3. Connectivity curves in different network size.

Fig. 4 reflects the number of nodes required to be deployed to achieve different coverage and connectivity rates without the boundary influence. Compared with the boundary influence, the number of nodes deployed increases slightly, and with the increase of nodes, node density will become larger, so the boundary influence becomes lower.

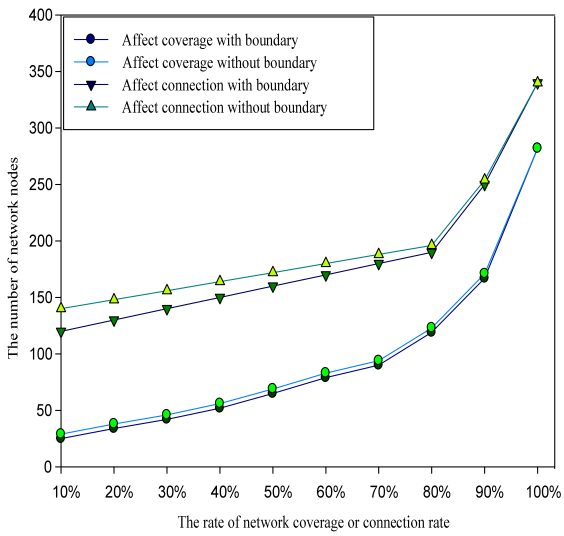

Fig. 4. Curves of network coverage rate/ connectivity rate with/without boundary influence.

5. Conclusion

In view of the network coverage and connectivity of the random deployment of nodes for wireless sensor network, the relation model of the sensor node and the target node were provided. Considering the boundary influence, coverage and connectivity probability model was also provided. It can simplify the computational complexity of network coverage and connectivity to improve the efficiency of the algorithm execution, and thus solve the number of nodes required to deploy more accurately meeting certain network coverage and connectivity rate requirements. Finally, the correctness of the theoretical solution and validity of the algorithm are verified by the simulation results. The main work thereafter was the study of the effective coverage of the irregular region and the entire network energy savings based on sensor network.

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