A Deterministic Sensor Node Deployment Method with Target Coverage and Node Connectivity

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Abstract. The paper proposes a deterministic node deployment method based on grid scan to achieve targets coverage and nodes connectivity. Target area is divided into girds from which the most suitable one is selected to place the next node. In the coverage phase, the grid where the sensor node can sense the most targets and have the best coverage level is selected to place the next sensor node. To make the sensor nodes connected, first, the sensor nodes are divided into connected groups, then, the grid where the relay node can connect the most groups and have the best connectivity level is selected to place the next relay node. Simulation experimental results show that the method can achieve target coverage with the least sensor nodes and sensor node connectivity to a great extent.

Keywords: WSNs (wireless sensor networks), deployment, coverage, connectivity, target monitor.

1 Introduction

In recent years, sensor networks have emerged as promising platforms for many applications, such as environmental monitoring, battlefield surveillance, and health care [1], [2]. The sensor node deployment is the first and very important step in WSNs. There are mainly two deployment ways including random deployment and deterministic deployment. The former simply scatters (for example, air drop) a sufficiently large number of sensors over the monitoring region with the expectation that the sensor nodes that survive the air drop will be able to adequately monitor the target region. This is usually adopted where human can not get in touch easily such as battlefields. However, when the place is easy for human to get in, the latter way can be chosen to deploy the sensor nodes manually.

Many researches have been done on coverage [3-5,7] and connectivity problems [6] in WSNs. References [8] and [9] discuss some deployment pattern and prove that the strip-based patterns are absolutely optimal to achieve both coverage and 1- or 2-connectivity. Yanli Cai et al. [10] organize the directions of sensors into a group of non- disjoint cover sets to extend the network lifetime in directional sensor networks.

H. Deng et al. (Eds.): AICI 2011, Part II, LNAI 7003, pp. 201–207, 2011.

Jie Wang and Ning Zhong [11] study minimum-cost sensor placement on a bounded 3D sensing field to monitor target points with several types of sensors with different sensing ranges and different costs. Xiaochun Xu and Sartaj Sahni [12] develop an integer linear programming formulation to find the minimum cost deployment of sensors that provides the desired coverage of a target point set and propose a greedy heuristic for the problem. Mihacla Cardei et al. [13] propose an efficient method to extend the sensor network life time by organizing the sensors into a maximal number of set covers that are activated successively. Chia-Pang Chen et al. [14] project a novel coverage-preserving algorithm that is able to prolong the lifetime and to maximize the coverage. Jing He et al.[15]introduce failure probability into target coverage problems, model the solution as the Maximum Reliability Sensor Covers (MRSC) problem and design a heuristic greedy algorithm that efficiently compute the maximal number of reliable sensor covers. Xingfa Shen et al. [16] propose a re-deployment which randomly places some sensors and then deploys some sensors manually to meet any *k*-covered rate in some regions according to application requirements.

Most of the researches mentioned aiming at targets' coverage and monitor are based on sensor nodes with big density that have been scattered in the interest area. However, in some cases such as fields with limited certain targets to be covered and monitored, deterministic deployment can use much fewer sensors to cut down cost greatly.

The paper proposes a simple deterministic deployment method which considers coverage and connectivity at the same time based on grid scan**.** The target area is divided into grids from which the most suitable one is selected to place the next node to cover targets or connect sensor nodes. In section 2, grid selection for sensors' placement to cover targets is developed. Section 3 shows how to add fewest relay nodes to connect the sensor nodes generated in section2. Simulation experimental results are presented in section 4. Conclusions and further work are showed in section 5.

2 Targets Coverage

To achieve targets coverage, placing a sensor node in each target point can get the best coverage level. However when the density of target points is large and the demanded coverage level is not very high, more than one targets can be sensed by a sensor node placed suitably. The binary coverage model is used to denote how a sensor node can sense a target.

2.1 Binary Coverage Model

The paper adapts binary coverage model. Equation (1) shows the binary sensor model [17][18] that expresses the coverage $c(s_i)$ of a target point p by the sensor s_i .When the distance between p and s_i $d(s_i p)$ is smaller than sensing radius r_s, s_i can sense p, otherwise can not.

$$c(s_i) = \begin{cases} 1, & if\ d(s_i, p) < r_s \\ 0, & otherwise \end{cases} \tag{1}$$

2.2 Coverage Algorithm

Target area is divided into square grids to denote positions of targets and sensor nodes. The smaller the grid size is, the more accurate the position is.

To cover the targets with the least nodes, the grid where the sensor can cover the most targets should be chosen first to place the next sensor node. Grid *m* should be chosen to place the next node in equation (2) where *s(i)* denotes the sensor node amount sensed by the grid *i*. After a new grid has been chosen, the targets covered by the sensor placed at the grid should be taken away from the targets needed to be covered to prevent repetitive coverage.

$$m = \arg\max(s(i)) \tag{2}$$

When selecting the next grid, there may exist more than one grids that cover the same most targets, in this case, the grid with the shortest distance to the farthest target should be chosen in order to achieve better overall coverage. Grid *n* in Equation (3) should be chosen to place the next sensor node where *G* denotes the grid set that can cover the same most targets and *T* denotes the target set that can be covered by the sensor node at the grid *i*.

$$n = \arg\min_{i \in G} \max_{t \in T}(d(i,t)) \tag{3}$$

3 Sensor Nodes Connectivity

The sensor nodes for targets coverage may not connected, so relay nodes need be placed to connect sensor nodes so that data can be transmitted and gathered. First, sensor nodes are divided to connected groups. Then, the grid where relay node can connect the most groups is selected.

3.1 Sensor Nodes Grouping

Sensor node *i* and *j* can communicate with each other directly only when their distance $d(s_i, s_j)$ is smaller than the communication radius r_c which can be seen in equation (4). When two sensor nodes can communicate with each other, they are said to be a neighbor node of each other. The sensor node group is said to be connected when each of them has at least one neighbor in the group (equation (5)).

$$d_{ij} = \begin{cases} 1, & if\ d(s_i, s_j) < r_c \\ 0, & otherwise \end{cases} \tag{4}$$

Sensor nodes generated in the coverage phase may not be connected among which some sensor nodes are connected. No relay node is needed to be placed to connect sensor nodes in the same connected group. Relay nodes are only needed to be placed to connect the non-connected groups. The sensor nodes are divided into some connected groups neither of which is connected. Two sensor nodes group g_i and g_j are said to be connected if there exists at least one sensor node in g_i who has at least one neighbor in g_j. Otherwise they are said to be non-connected which can be seen in equation (6).

$$g_i = \begin{cases} 1, & if\ \forall x \in g_i\ \exists y \in g_i\ d(x,y) < r_c \\ 0, & otherwise \end{cases} \tag{5}$$

$$c_{ij} = \begin{cases} 1, & if\ \exists x \in g_i\ \exists y \in g_j\ d(x,y) < r_c \\ 0, & otherwise \end{cases} \tag{6}$$

3.2 Groups Connectivity

Target area is divided into square grids to denote positions of relay nodes and sensor nodes. In order to place the least relay nodes, the grid where a relay node can connect the most groups should be chosen to place the next relay node. The distance between a relay node r_i and group j is defined in equation (7). The relay node r_i is assumed to be connected with group j when $d_{rj}<r_c$. The sensor node with the nearest distance to the relay node in group j is said to be the communication node between r_i and group j.

$$d_{rj} = \min(d(r_i, s_k)) \quad s_k \in group\ j \tag{7}$$

After a new grid has been chosen, the sensor nodes in all the groups connected by the new relay node placed at the grid should be combined into one group. Looping continues until there does not exist a grid where sensor can connect more than one groups.

When choosing the grid to place the next relay node, there may exist more than one grids where the relay node can connect the same largest number of groups. In this case, the grid where the relay node is nearest to its furthest communication node should be chosen to place the next relay node to achieve the better overall connectivity. In equation (8), the set R denotes all the grids where relay nodes can connect the same largest number of groups, the set P is consisted of the communication nodes of the relay node r_i at each grid in R.

$$g_n = \arg\max_{r_i \in R} \min_{t \in P}(d(r_i, t)) \tag{8}$$

4 Experiment Results

Suppose in an area whose length and width are all 100 meters, 10 and 20 target points are generated randomly. The targets' coordinates are with the accuracy of 0.1 meter.

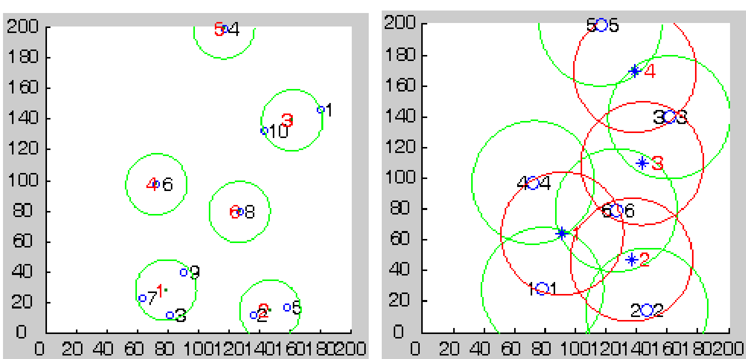
The sensor radius and communication radius are 20 meters and 40 meters respectively. The grid side is 0.1 meter.

Fig.1 and Fig.2 show the experiment results when the target number is 10 and 20 respectively. In (a) of Fig.1 and Fig.2, the blue circles denote the target points behind which the black numbers denote the target serial number. The green dots denote the sensor nodes in front of which the red numbers denote the order to place the sensor node to cover target points and the green circles denote the coverage domain of the sensor node.

In Fig.1 (b) and Fig.2 (b), the blue circles denote sensor nodes generated in (a), and the black numbers behind and in front of the blue circles denote the sensor node's serial number and its group number respectively. The * characters denote the relay nodes to connect groups, behind which the red numbers denote the order to place the relay node and the red circles and green circles denote the communication domain of the relay node.

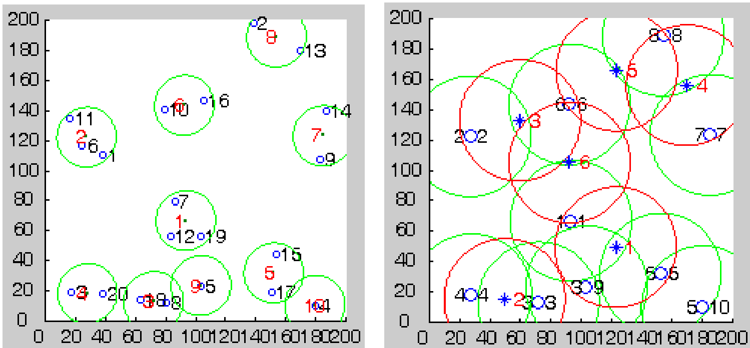
In Fig.1 (a), sensor node 2 and sensor node 3 both can coverage two target points. However, sensor node 2 can achieve better coverage, that is, it can sense its two targets 2 and 5 more easily than sensor 3. So the grid at sensor 2 is selected to place the second sensor node. Likewise in Fig.2 (a), the grid at the sensor node 1 is selected to place the first sensor instead of the grid at the sensor node 2.

In the six sensor nodes placed for coverage in Fig.1 (a), none of them can communicate with one another. So they are divided into six groups, which can be seen in Fig.1 (b). When selecting grids to connect groups, relay node 1 can connect three groups including group 1, 4 and 6 and it has the better communication situation than the relay node placed at any other grid. After relay node 1 is placed, group 1, 4, 6 are connected and combined to group 1. Then there exist four groups needed to be connected, the grid at relay node 2 where relay node can connect the most groups and has the best communication situation, so it is chosen to place the second relay node to combined group 1 and group 2.



(a) coverage (b) grouping and connectivity

Fig. 1. Coverage and connectivity(target number is 10)



(a) coverage (b) grouping and connectivity

Fig. 2. Coverage and connectivity (target number is 20)

5 Conclusions and Further Work

The paper proposes a simple and valid method to achieve target coverage and sensor node connectivity based on grid scan. The target area is divided into grids. It can achieve target coverage using the least sensor nodes and sensor node connectivity to a great extent.

In coverage phase, the grid where sensor node can cover the most target points and have the most coverage level is selected to placed the next sensor node, then the targets covered by the new sensor nodes are removed from the targets set waiting for coverage, and the next grid is selected to place the next sensor node until each target is covered.

The sensor nodes generated in the coverage phase may not be connected. They are divided into connected groups firstly in the connectivity phase, then the grid where a relay node can connect the most groups and has the best connectivity level is selected to place the next relay node, then the groups connected by the new relay node is combined to one group, select the next grid to place the new relay node until no more than one groups are connected.

There are still some shortages in the proposed method. Firstly, the paper adopts the binary model, in which the sensing result is either success or failure. It is not in accordance with the actual situation, introducing a probability model to the method is the future work. Secondly, sensor nodes may be still not connected after the connectivity algorithm, so researches on how to place sensor nodes to achieve overall connectivity need to be done.

Acknowledgment. The paper is supported partly by National Spark Program (2010GA6 00001).

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