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The fault tolerant connected sensor cover algorithm for discrete targets

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***Abstract*—The connected sensor cover, which is a set of connected sensors that cover distributed targets, is widely considered as one of methods that reduce network energy and communication costs. However, connectivity or coverage of the connected sensor cover may be lost in case that a sensor is down because of some kind of failure.**

In the present paper, we propose a distributed connected sensor cover algorithm for constructing a fault tolerant sensor cover, which is the 2-connected sensor cover with 2-coverage of discrete targets. The experimental results show that our proposed algorithm constructs the fault tolerant connected sensor cover with small overhead factor.

I. Introduction

Sensor network is a kind of wireless communication network that consists of a number of self-organized sensors. Each sensor can sense given targets if the target is in the sensing range, and communicate with the other sensor if the sensor is in the communication range. In the sensor network, a set of sensors is called connected if any two sensors in the set can communicate using the other sensors. In addition, a set of sensors is called cover if all targets are covered with sensors in the set. Thus, the connected sensor cover is defined as a set of connected sensors that cover all targets.

On the other hand, each sensor generally works with non-rechargeable battery, and a number of methods are considered to reduce network energy costs. Since most of energy of sensor network is spent with communication of data between each sensors, the smaller number of sensors achieves less communication costs. Therefore, the connected sensor cover with a small number of sensors is widely considered as one of methods that reduce network energy and communication costs.

A number of algorithms [1], [2] have been proposed for constructing the connected sensor cover for discrete targets. For example, Lu et al. [2] has proposed a distributed algorithm for constructing connected sensor cover for discrete targets. However, connectivity and coverage for the connected sensor cover may be lost in case that a sensor is down because of some kind of failure.

In the present paper, we propose a distributed algorithm for constructing a fault tolerant connected sensor cover, which is the 2-connected sensor cover with 2-coverage of discrete targets. The sensor cover is called 2-connected if the sensor cover is still connected in case of removing any sensor. In addition, the sensor cover is called 2-cover if the set of sensors covers all targets in case of removing any sensor.

We implement our proposed algorithm in simulation environment and review the propriety of the proposed algorithm. The experimental results show that our proposed algorithm constructs the fault tolerant connected sensor cover with small overhead factor.

II. Preliminaries

A. Sensor model

A sensor network $G = (V, E)$ consists of a set of sensors $V = \{I_0, I_1, ..., I_{n-1}\}$. Each sensor $I_k \in V$ has a unique ID, and is associated with a sensing radius s and a transmission radius t. We assume that each sensor I_k senses a circular region S_k whose radius is s, and also assume that there is a communication link $e_{i,j} \in E$ between the two sensors I_i and I_j if and only if distance between the two sensors is less than t.

B. Connected sensor cover for discrete targets

The connected sensor cover for discrete targets is formally defined as follows.

Definition 1 (Connected sensor cover for discrete targets): Let $G = (V, E)$ be a given sensor network such that $V = \{I_0, I_1, \cdots I_{n-1}\}$, and also let S_i be a sensing area of sensor I_i. We also assume $T = \{T_0, T_1, \ldots, T_{m-1}\}$ is a set of given discrete targets. Then, a set of sensors $M = \{I_{i_0}, I_{i_1}, \cdots, I_{i_{n-1}}\}$ $(M \subseteq V)$ is a connected sensor cover for discrete targets T if and only if the following two conditions hold.

1) $T \subseteq S_{i_0} \cup S_{i_1} \cdots \cup S_{i_{n-1}}$.
2) A subgraph induced by M is connected. □

C. 2-connectivity and 2-coverage

The 2-connectivity and 2-coverage of the connected sensor cover is formally defined as follows.

Definition 2 (2-connectivity and 2-coverage): A connected sensor cover M called 2-connected if and only if the sensor cover is still connected in case of removing any sensor from M. In addition, M is called 2-cover if and only if M is the sensor cover in case of removing any sensor from M. □

III. A DISTRIBUTED ALGORITHM FOR FAULT TOLERANT CONNECTED SENSOR COVER FOR DISCRETE TARGETS

A. Ideas for the algorithm

In the distributed algorithm, each sensor can obtain informations for the other sensors by communications between sensors only. Therefore, if each sensor does not communicate with the other sensors, each sensor knows informations for discrete targets in the sensor's sensing area, and no informations for the other sensors, such as the number of the sensors in the sensor network or the number of targets, can be obtained. On the other hand, if each sensor communicate with a large number of sensors, communication costs increase and some unnecessary sensors may be added to the connected sensor cover.

To avoid the problem, each sensor collects informations for sensors within k-hops, where k is a given parameter. The sensor, which collects the informations within k-hops, is called *coordinator*, and the coordinator creates a subgraph using collected informations, considers 2-connectivity and 2-coverage with a subgraph induced by the collected informations, and deletes redundant sensors in a subgraph.

However, in case that a sensor is redundant sensor at kth-hops, the deletion of the sensor may cause disconnection of a whole connected sensor cover. Therefore, we define a redundant sensor as follows.

Definition 3 (A redundant sensor): Let $G = (V, E)$ be a given sensor network such that $V = \{I_0, I_1, \cdots I_{n-1}\}$, and also let S_i be a sensing area of sensor I_i. We also assume $T = \{T_0, T_1, \ldots, T_{m-1}\}$ is a set of given discrete targets, and I_c is a coordinator. Then, I_r is called a redundant sensor for I_c if and only if the following three conditions hold.

1) Each $t \in T$ is covered with at least two sensing areas in $\{S_0, S_1, \cdots S_{n-1}\} - \{S_r\}$.
2) Let G' is a subgraph such that I_r is deleted from V. Then, G' is 2-connected.
3) I_r is not at kth-hops from I_c. □

B. An overview of the algorithm

Based on the above idea for redundant sensors, the proposed distributed algorithm consists of the following four steps.

Step 1: Each sensor randomly choose whether the sensor become a coordinator, or not. If the sensor become a coordinator, the following steps are executed.
Step 2: The sensor collects all informations within k-hops.
Step 3: The sensor computes redundant sensors, which is defined by Definition 3.
Step 4: A coordinator notifies all redundant sensors within k-hops. The notified sensors are terminated.

IV. EXPERIMENTAL RESULTS

In this section, we compare our proposed algorithm and a centralized algorithm in simulation environment, and compare the number of sensors and communication costs in the obtained connected sensor covers.

We assume that region is a 100×100 square area. In addition, 2500 sensors and 100 discrete targets are randomly located in the region. We also assume that sensing and transmission radiuses are $s = 4$ and $t = 8$, respectively. Each coordinator collects informtions in $k = 2, 3, 4$ hops.

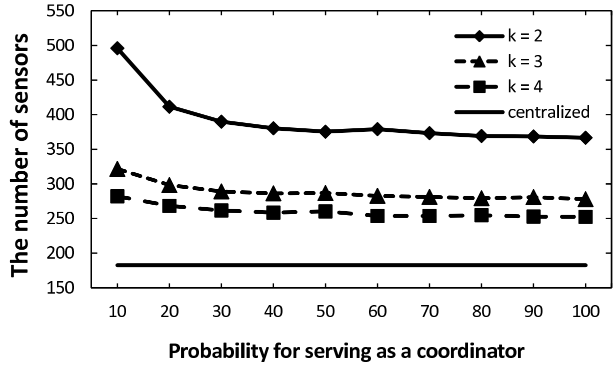

Fig. 1. The number of sensors in connected sensor covers

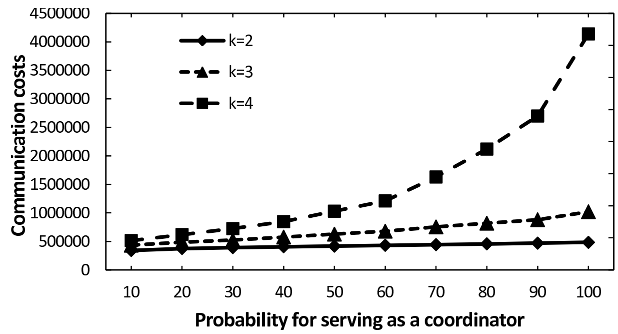

Fig. 2. Communication costs

Figure 1 shows the number of sensors in the obtained connected sensor covers. The result shows that our proposed algorithm for $k = 4$ has obtained the connected sensor conver with small overhead factor.

Figure 2 shows communication costs of the proposed algorithms. The communication cost is simply defined as sum of the number of communication among the sensors. The result shows that communication costs increase according to k.

V. CONCLUSIONS

In the present paper, we have proposed a distributed algorithm for constructing the connected sensor cover that satisfies 2-connectivity and 2-coverage of discrete targets. The experimental result shows that our proposed algorithm for $k = 4$ constructs the fault tolerant connected sensor cover with small overhead factor.

In the future research, we are considering a self-stabilizing algorithm which recovers from a single sensor.

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