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An effective allocation method of ZigBee sensor nodes using a discrete particle swarm optimizer

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Abstract: This paper proposes a method to find effective allocations of ZigBee coordinators using the Discrete Particle Swarm Optimizer (DPSO). In the proposed method, an observation area is represented as a grid space. For a given ZigBee end device location, it is decided whether each ZigBee coordinator is allocated or not on each intersection of the grid. Such binary state variables are optimized by the DPSO. In the simulation experiments, the proposed method is evaluated to some of given ZigBee end device locations. It is shown that the proposed method can provide effective allocations of ZigBee coordinators.

Keywords: ZigBee sensor networks, Coordinator, Discrete Particle Swarm Optimization

I. INTRODUCTION

ZigBee sensor networks are known as a wireless technology of an open global standard [1] [2]. The ZigBee sensor networks have a wide range of applications, such as voice services [3] and vehicular environments [4]. Also, many protocols for ZigBee sensor networks have been proposed. ZigBee sensor nodes are classified into a Full-Function Device (FFD) and a Reduced-Function Device (RFD). The RFD is a low-cost device and can be a ZigBee end device which monitors status information around it, such as temperature, light intensity, and moving objects. The FFD can be not only a ZigBee end device but also a ZigBee coordinator or a ZigBee router which gathers sensing information transmitted from RFDs via wireless communication.

The basic network topologies of the ZigBee sensor networks are star networks, cluster tree networks, mesh networks, and so on. This paper focuses on the star networks. In the networks, one coordinator and end devices exist; routers do not exist. Each end device does not have routing functions; it only transmits its own sensing information directly to a coordinator and does not relay sensing information from the other devices. Since multi-hop wireless communication is not required to the end devices, energy consumption of each end device can be saved. Hence, long-term observation is possible. In addition, constructing cluster tree networks of plural coordinators, large scale observation is also possible. However, it is needed that all end devices can communicate directly to one of coordinators via wireless communication, since each end device does not have routing functions. Therefore, effective allocations of coordinators in an observation area should be considered. That is, the number of coordinators and their locations should be optimized. This is also regarded as a problem to design a kind of cluster tree networks.

This paper proposes a method to find effective allocations of coordinators using a discrete particle swarm optimizer (DPSO) [5]. In the DPSO, each particle having binary state variables represents a solution of an objective function, and moves in a multidimensional search space based on its own and other particles' experiences. As each particle effectively interacts to each other, an optimum solution for the objective function can be found. The DPSO can fast solve various optimization problems although the algorithm uses only simple and fundamental operations. In the proposed method, an observation area is represented as a grid space. For a given end device location, it is decided whether each coordinator is allocated or not on each intersection of the grid. Such binary state variables are optimized by the DPSO. Desired allocations of coordinators are defined as follows: all end devices can communicate directly to one of coordinators with the minimum number of coordinators. The objective function is designed by considering them. In the simulation experiments, the proposed method is evaluated to some of given end device locations. It is shown that the proposed method can provide effective allocations of coordinators.

II. ZIGBEE SENSOR NETWORKS

ZigBee is one of the world standards on a short distance wireless sensor network [1]. The ZigBee belong to the WPAN (Wireless Personal Area network), and can construct low-cost and low-power networks. Specification of the ZigBee in a basic part is standardized as IEEE 802.15.4 [2]. The typical data-transfer speed is from 20kbps to 250kbps. Each ZigBee sensor nodes can operate during several years by batteries. ZigBee sensor nodes are classified into a Full-function Device (FFD) and a Reduced-function Device (RFD). The RFD is a low-cost device and can be a ZigBee end device which monitors status information around it, such as temperature, light intensity, and moving objects. The FFD can be not only a ZigBee end device but also a ZigBee coordinator or a ZigBee router which gathers sensing information transmitted from RFDs via wireless communication.

The basic network topologies of the ZigBee sensor networks are star networks, cluster tree networks, mesh networks, and so on (see Fig.1). In all the networks, one coordinator controls whole of their networks. In the star networks, a root node becomes a coordinator and leaf nodes become end devices; routers do not exist in the networks. In the cluster networks, a root node becomes a coordinator, leaf nodes become end devices, and the other nodes become routers. In the mesh networks, one node becomes a coordinator and all the other nodes become routers.

This paper focuses on the star networks. In the networks, each end device does not have routing functions; it only transmits its own sensing information directly to a coordinator and does not relay sensing information from the other nodes. Since multi-hop wireless communication is not required to end devices, energy consumption of each end device can be saved. Hence, long-term observation is possible. In addition, constructing cluster tree networks of plural coordinators, large scale observation is also possible as shown in Fig.2. However, it is needed that all end devices can communicate directly to one of coordinators via wireless communication, since each end device does not have routing functions. Therefore, effective allocations of coordinators in an observation area should be considered. That is, the number of coordinators and their locations should be optimized. This is also regarded as a problem to design a kind of cluster tree networks.

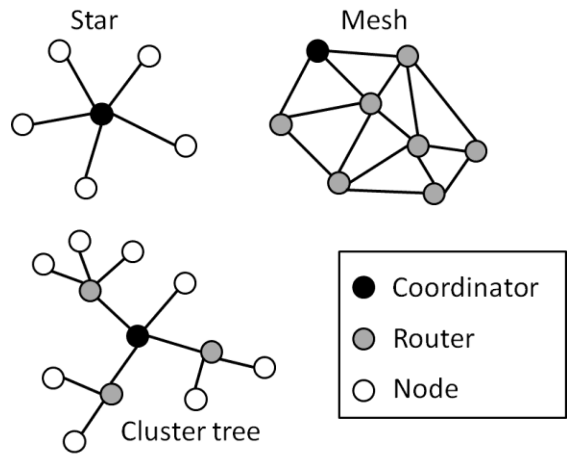

Fig.1. Basic topologies of ZigBee sensor networks.

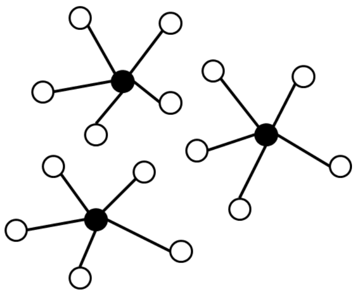

Fig.2. Effective allocations of plural coordinators.

III. DISCRETE PARTICLE SWARM OP TIMIZER

The Particle Swarm Optimizer (PSO) is known as a kind of metaheuristic algorithms, and can fast solve solutions in various optimization problems, compared with the other optimization methods [6]. The PSO is modeled by particles with positions and velocities in multidimensional search space. Each particle has a personal best solution as a search history of its particle and shares a global best solution as a search history of all particles. The Discrete Particle Swarm Optimizer (DPSO) is a discrete binary version of the PSO [5]. The DPSO can be applied to various combinational optimization problems. Basic algorithm of the DPSO is described as follows.

(step1) Set positions and velocities of each particle at random.

(step2) Update the positions of each particle by Equation (1). They are decided as binary values by substituting the current velocities to the sigmoid function (2), and comparing them with uniform random numbers.

$$\begin{aligned} &if \;\; \rho < sig(v_i^{k+1}) \;\; then \;\; x_i^{k+1} = 1 \\ &\qquad\qquad\qquad\qquad else \;\; x_i^{k+1} = 0 \end{aligned} \tag{1}$$

$$sig(v_i^{k+1}) = \frac{1}{1+\exp(-v_i^{k+1})} \tag{2}$$

where x_i^k and v_i^k are the position and velocity of the i -th particle at the k -th iteration, respectively. $sig(\cdot)$ is the sigmoid function, and ρ is a uniform random number from 0 to 1.

(step3) Calculate evaluation values of each particle.

(step4) Update each personal best solution ($pbest_i$).

(step5) Update global best solution ($gbest$).

(step6) Update the velocities of each particle by Equation (3).

$$\begin{aligned} v_i^{k+1} = w \cdot v_i^k + c_1 \cdot r_1 \cdot (pbest_i - x_i^k) \\ + c_2 \cdot r_2 \cdot (gbest - x_i^k) \end{aligned} \tag{3}$$

where w is an inertia coefficient for the current velocity vector. c_1 is a weight coefficient for personal best position vector. c_2 is a weight coefficient for global best position vector. r_1 and r_2 are uniform random numbers from 0 to 1.

(step7) Repeat from step2 to step6 until the number of iterations or evaluation value of a solution reaches a predetermined value.

IV. PROPOSED METHOD

In this section, the proposed method is explained and typical simulation results are shown. We apply the DPSO to the ZigBee coordinator allocation problem as follows. The observation area is delimited as the grid space. Each intersection of the grid represents a candidate location of coordinators, and the combination whether coordinators are allocated is optimized by the DPSO. The purpose of this problem is that all end devices are connected directly by one hop with one of coordinators via wireless communication. In such a constraint condition, the number of coordinators is minimized. The evaluation function is given by Equation (4).

$$F = \frac{1}{f_1} + W f_2 \tag{4}$$

where F is an evaluation value. f_1 is the number of coordinators, f_2 is the number of end devices which can directly connect with one of coordinators, and W is a weight parameter.

End devices (nodes) are allocated in the observation area at random. The size of the observation space is 20×20. The radio range of nodes is 5. The number of particles in the DPSO is 10. The number of cycles for a single trial is 100. In all the experiments, the DPSO uses the fixed parameter values:

$$w = 1.0 \;,\; c_1 = c_2 = 1.0 \;,\; W = 1.0 .$$

First, we show the simulation results for 10 nodes. Fig.3 shows the example allocation of coordinators obtained by the DPSO when the grid is 5×5. In the figure, obtained minimum number of coordinators is 5. Fig.4 shows the results when the grid is 9×9. In the figure, obtained minimum number of coordinators is 4. As compared with the case of 5×5, the number of candidate locations of coordinators increases. Then, the obtained minimum number of coordinators decreases. Table 1 shows the number of allocation patterns and their obtained times for 100 trials.

Next, we show the simulation results for 20 nodes. Figs.5 and 6 show the example allocations when the grid is 5×5 and 9×9, respectively. Table 2 shows the number of allocation patterns and their obtained times for 100 trials.

Depending on the number of nodes and their locations, total number of effective allocation patterns of coordinators change. However, it should be noted that the proposed method based on the DPSO can find acceptable solutions for all trials.

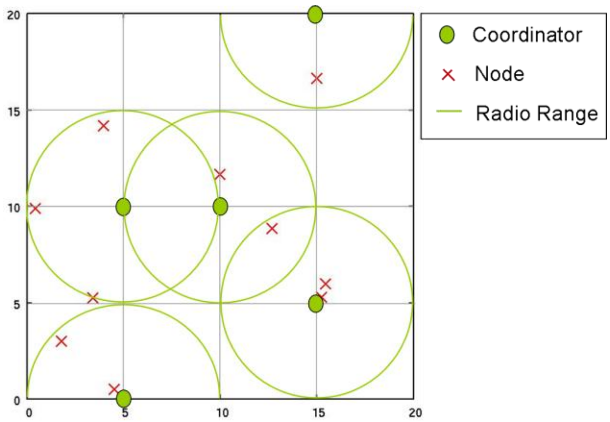

Fig.3. Allocation result (10 nodes, 5×5 grid).

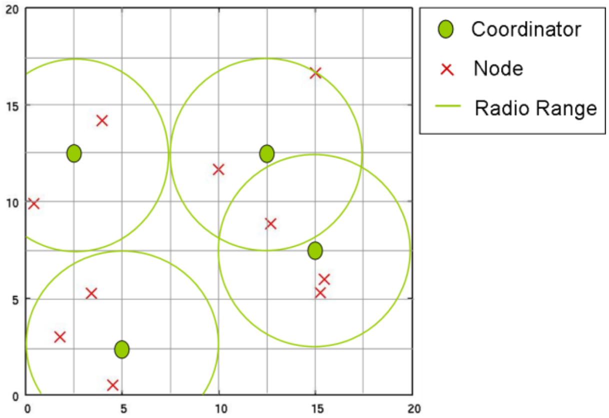

Fig.4. Allocation result (10 nodes, 9×9 grid).

Table 1. Number of allocation patterns (10 nodes).

Grid	Number of coordinators	Obtained frequency	Number of patterns
5×5	5	79	28
	6	21	20
9×9	4	35	35
	5	57	57
	6	8	8

VI. CONCLUSION

This paper has proposed an application of the DPSO to ZigBee sensor networks. The proposed method can provide effective allocations of ZigBee coordinators such that all ZigBee end devices can connect directly with one of coordinators via wireless communication, as minimizing the number of coordinators. Also, the proposed method can provide various allocation patterns by changing initial values. If the grid becomes finer, the problem becomes more difficult. However, the possibility that a better solution can be discovered increases. This means that allocations of the coordinators can be effectively optimized by the DPSO by appropriately setting the grid considering the radio range and the scale of problems.

Future problems include (1) more detailed analysis of searching performances, (2) application of the method for finding plural acceptable solutions.

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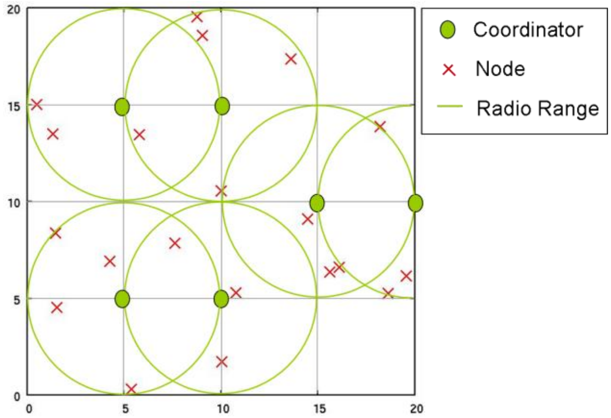

Fig.5. Allocation result (20 nodes, 5×5 grid).

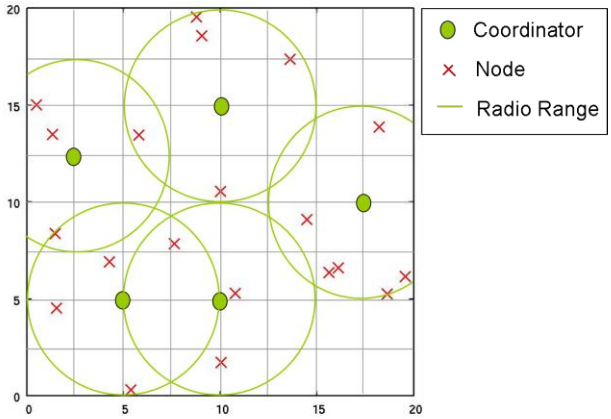

Fig.6. Allocation result (20 nodes, 9×9 grid).

Table 2. Number of allocation patterns (20 nodes).

Grid	Number of coordinators	Obtained frequency	Number of patterns
5×5	6	55	14
	7	39	28
	8	6	6
9×9	5	3	3
	6	26	26
	7	50	50
	8	21	21