2011 International Symposium on Nonlinear Theory and its Applications
NOLTA2011, Kobe, Japan, September 4-7, 2011

Discrete PSO with refractoriness for Finding Plural Acceptable Solutions

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Abstract: This paper proposes a method to find effective allocations of coordinators in ZigBee sensor networks using the Discrete Particle Swarm Optimizer with refractoriness term. 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 proposed method. In the simulation experiments, the proposed method is evaluated to some of given ZigBee end device locations, and is compared with common DPSO method. It is shown that the proposed method was able to discover more effective solutions than the common DPSO method.

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 optimum cluster tree networks.

An effective allocation method of ZigBee sensor nodes using a discrete particle swarm optimizer (DPSO, [5]) is proposed [6]. 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. But, there are problems in the common DPSO. When the common DPSO falls into the local optima, it is difficult to escape from them. Moreover, the search for the multiple solutions is impossible in the common DPSO. In a real problem, it is desired that the specialist and the engineer can select one of executable solutions from multiple solution candidates. Then, we propose DPSO with refractoriness term, and an application of this algorithm to ZigBee sensor networks.

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. 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). 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 optimum cluster tree networks.

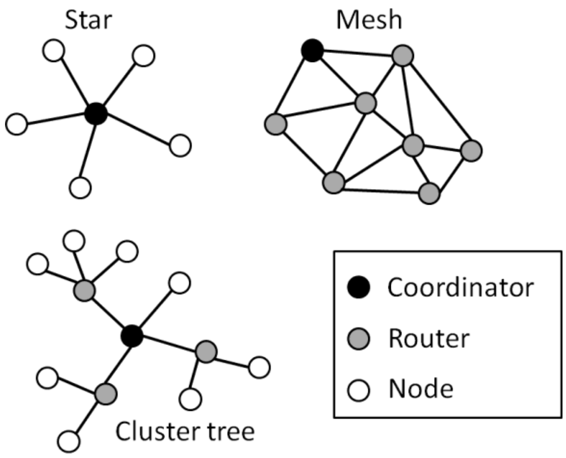

Fig.1. Basic topologies of ZigBee sensor networks.

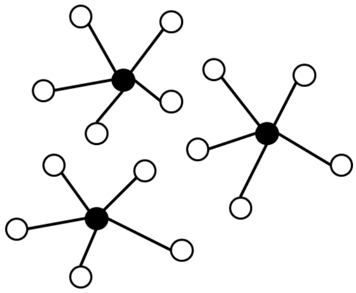

Fig.2. Effective allocations of plural coordinators.

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 [7]. 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.

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

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

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 Eq uation (3).

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

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

There are problems in the common DPSO. When the common DPSO falls into the local optima, it is difficult to escape from them. Moreover, the search for the multiple solutions is impossible in the common DPSO. In a real problem, it is desired that the specialist and the engineer can select one of the executable solutions from the multiple solution candidates. Then, we propose DPSO with refractoriness term. The proposed method can escape from local optima and search for the multiple solutions. In the proposed method, velocities of each particle are updated by Equation (4).

$$v_i^{k+1} = w \cdot v_i^k + c_1 \cdot r_1 \cdot (pbest_i - x_i^k) + c_2 \cdot r_2 \cdot (gbest - x_i^k) + u_i^{k+1} \quad (4)$$

where u_i^k is refractoriness term of the i-th particle at the k-th iteration.

u_i^{k+1} is given by Equation (5).

$$u_i^{k+1} = \delta_1 \cdot u_i^k - \delta_2 \cdot sig(v_i^k) + \delta_3 \quad (5)$$

where δ_1 is a dumping parameter, δ_2 is a gain parameter, and δ_3 is a offset parameter.

Basic dynamics of the refractoriness term is explained as follows. If v_i^k increases, u_i^{k+1} decreases and it suppresses the increase of v_i^k. This scheme can improve excessive conversion to local optima. Such a refractoriness term can be found in the chaotic neural networks[8].

V. CODING

We apply the DPSO and the proposed method 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 each method. Note 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 (6).

$$F = \frac{S^{-(f_{all} - f_1)}}{f_2} \quad (6)$$

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

VI. EXPERIMENT

In this section, the solution performances of the proposed method and DPSO are compared. End devices (nodes) are allocated in the observation area at random. The size of the observation space is 20×20. The number of nodes is 20. The radio range of nodes is 5. The number of particles in each method is 10. The number of cycles for a single trial is 200. In all the experiments, each method uses the fixed parameter values:

$w = 1.0$, $c_1 = c_2 = 1.0$, $S = 100$.

The proposed method uses the fixed parameter values:

$\delta_1 = 1.0$, $\delta_2 = 0.19$, $\delta_3 = 0.5$, $\rho = 0.5$

Note that ρ is decided to be a fixed value in the proposed method.

Fig.3 shows the example allocation of coordinators obtained by the proposed method when the grid is 5×5. Table 1 shows the number of allocation patterns in 5×5 grid for 1000 trials. Table 2 shows the number of allocation patterns in 9×9 grid for 1000 trials.

In the case of 5×5 grid, the minimum number of coordinators becomes 6 in both methods. Also, 14 different allocation patterns consisting of 6 coordinators can be obtained. As comparing frequency to obtain each pattern, the performance of the proposed method is worse than that of the common DPSO method. However, in the proposed method, particles move continuously by the refractoriness term. Hence, the proposed method can search solution space widely. In the case of 9×9 grid,

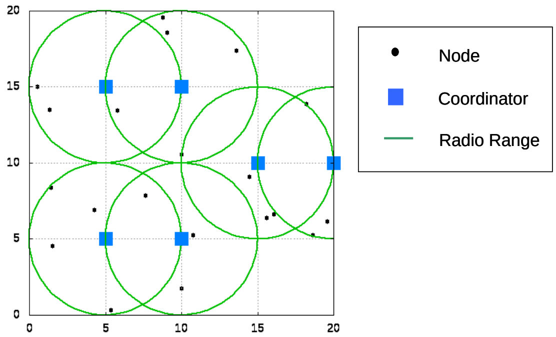

Fig.3. Allocation result (5×5 grid).

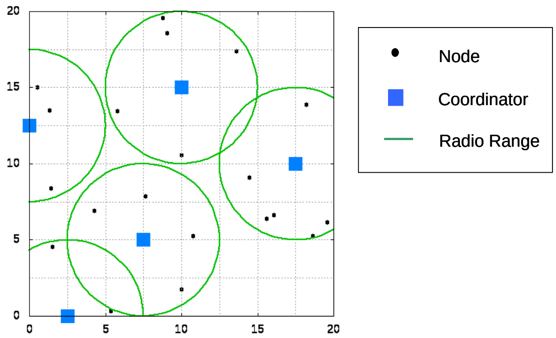

Fig.4. Allocation result (9×9 grid).

Table 1. Number of allocation patterns (5×5 grid).

Number of coordinators	Frequency to obtain each pattern				Number of different allocation patterns (coordinator=6)
	9	8	7	6	
Proposed method	8	59	351	580	14
DSPO	0	30	363	607	14

Table 2. Number of allocation patterns (9×9 grid).

Number of coordinators	Frequency to obtain each pattern					Number of different allocation patterns (coordinator=5)
	9	8	7	6	5	
Proposed method	13	144	432	323	88	48
DSPO	19	251	526	177	26	25

the minimum number of coordinators becomes 5 in both methods. It should be noted that the proposed method can find feasible patterns more frequently and more different allocation patterns than the common DPSO method. The common DPSO falls into local optima consisting of 7 coordinators frequently. This means that for higher dimensional problems, the proposed method can escape from local optima by refractoriness, and the solution performance can be improved.

VII. CONCLUSION

This paper has proposed an application of the DPSO with refractoriness term to ZigBee sensor networks, and compared it with a common DPSO method. As a result, the proposed method was able to discover more effective solutions than the common DPSO. This tendency was remarkable for the higher dimensional problems. The effectiveness of the proposed method was able to be confirmed in the simulation experiments.

Future problems include (1) more detailed analysis of searching performances, and (2) experiments in more actual sensor network environments.

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