The Fifteenth International Symposium on Artificial Life and Robotics 2010 (AROB 15th '10),
B-Con Plaza, Beppu,Oita, Japan, February 4-6, 2010

Efficient Flooding Method for Wireless Sensor Networks Based on Discrete Particle Swarm Optimization Computing Multiple Forwarding Nodes Sets

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Abstract: In wireless sensor networks, flooding is required for the dissemination of queries and event announcements. The original flooding causes the overlap problems. In the original flooding, each sensor node receiving a broadcast message forwards it to its neighbors, resulting in a lot of collisions and duplicate messages. For dense wireless sensor networks, the impact caused by the original flooding may be overwhelming. The original flooding may result in the reduced network lifetime. Therefore, the selecting method of forwarding nodes for the dissemination of queries and event announcements is needed to prolong the lifetime of wireless sensor networks. This paper proposes a new efficient flooding method using discrete particle swarm optimization for the long-term operation of wireless sensor networks. We evaluate the proposed method using computer simulations. In simulation experiments, the performance of the proposed method is compared with those of the existing ones to verify its effectiveness.

Keywords: Query Dissemination, Efficient Flooding, Particle Swarm Optimization, Wireless Sensor Networks.

I. INTRODUCTION

A wireless sensor network, which is a key network to realize ubiquitous information environments, has attracted a significant amount of interest from many researchers [1]. In wireless sensor networks, hundreds or thousands of micro-sensor nodes, which are compact and inexpensive, are placed in a large-scale observation area and sensor information of each node is gathered to a sink node by inter-node wireless multi-hop communication. Each sensor node consists of a sensing function to measure the status (temperature, humidity, motion, etc.) of an observation point or object, a limited function on information processing, and a simplified wireless communication function, and generally operates on a resource of a limited power-supply capacity such as a battery. The suppression of communication loads is generally required for the long-term operation of wireless sensor networks.

In wireless sensor networks, flooding is required for the dissemination of queries and event announcements. The original flooding causes the overlap problems. In the original flooding, each sensor node receiving a broadcast message forwards it to its neighbors, resulting in a lot of collisions and duplicate messages. For dense wireless sensor networks, the impact caused by the original flooding may be overwhelming. The original flooding may result in the reduced network lifetime. Therefore, the selecting method of forwarding nodes for the dissemination of queries and event announcements is needed to prolong the lifetime of wireless sensor networks. The methods of [2-4] have been proposed in the existing studies to resolve or improve the overlap problems of the original flooding in disseminating queries or event data in a wireless sensor network. However, the gossiping of [2] may result in some nodes not receiving queries or event data. The existing methods of [3,4] can disseminate queries or event data to the whole nodes in a wireless sensor network, but can not select a most efficient and optimum forwarding nodes set for the dissemination.

This paper proposes a new efficient flooding method using discrete particle swarm optimization for the long-term operation of wireless sensor networks. The rest of this paper is organized as follows. In Section II, the proposed method is described. In Section III, the results of simulation experiments are reported, and the effectiveness of the proposed method is demonstrated by comparing the performance of it with those of the existing ones. Finally, the paper closes with conclusions and ideas for further research in Section IV.

II. PROPOSED METHOD

In this paper, a new efficient flooding method using Discrete Particle Swarm Optimization (DPSO), which detects not only an optimum forwarding nodes set but also multiple forwarding nodes sets, is proposed. By disseminating queries or event data over switching the selected forwarding nodes sets, the lifetime of wireless sensor networks can be extended. In this section, the

PSO method is first outlined. Then, the proposed method based on DPSO is described.

1. Particle Swarm Optimization

The PSO method belongs to the category of swarm intelligence methods. It was developed and first introduced as a stochastic optimization algorithm [5]. Currently, the PSO method is intensively researched because it is superior to the other algorithms on many difficult optimization problems [6-10]. The ideas that underlie the PSO method are inspired not by the evolutionary mechanisms encountered in natural selection, but rather by the social behavior of flocking organisms, such as swarms of birds and fish schools. The PSO method is a population-based algorithm that exploits a population of individuals to probe promising regions of the search space. In this context, the population is called a *swarm* and the individuals are called *particles*. In the PSO method, a multidimensional solution space by sharing information between a swarm of particles is efficiently searched. The algorithm is simple and allows unconditional application to various optimization problems.

Assume an n-dimensional search space S, and a swarm consisting of N particles. Each particle (The i th particle) has a position vector

$$\boldsymbol{x}_i = (x_{i1}, x_{i2}, \ldots , x_{in})^{\top} \in S,$$

and the velocity vector

$$\boldsymbol{v}_i = (v_{i1}, v_{i2}, \ldots , v_{in})^{\top} \in S,$$

where the subscript i ($i = 1, \ldots , N$) represents the particle's index. In addition, each particle retains the position vector $\boldsymbol{pbest}_i$ of the best evaluation value found by the particle in the search process and the evaluation value $f(\boldsymbol{pbest}_i)$, and also the position vector $\boldsymbol{gbest}$ of the best evaluation value among all particles and the evaluation value $f(\boldsymbol{gbest})$ as information shared in the swarm in the search process.

In the PSO method, each particle produces a new velocity vector $\boldsymbol{v}_i^{k+1}$ by linearly coupling the best solution [$\boldsymbol{pbest}_i^k$] found by the particle in the past, the best solution [$\boldsymbol{gbest}^k$] shared in the swarm, and the previous velocity vector $\boldsymbol{v}_i^k$ and moves to the next position $\boldsymbol{x}_i^{k+1}$, where the superscript k indicates the number of search iterations. At the k+1 search, the velocity vector $\boldsymbol{v}_i^{k+1}$ and the position vector $\boldsymbol{x}_i^{k+1}$ of the i th particle is updated by the following equations:

$$\begin{aligned} \boldsymbol{v}_i^{k+1} &= \omega \cdot \boldsymbol{v}_i^k + c_1 \cdot r_1 \cdot (\boldsymbol{pbest}_i^k - \boldsymbol{x}_i^k) \\ &\quad + c_2 \cdot r_2 \cdot (\boldsymbol{gbest}^k - \boldsymbol{x}_i^k) \\ \boldsymbol{x}_i^{k+1} &= \boldsymbol{x}_i^k + \boldsymbol{v}_i^{k+1} \end{aligned} \tag{1}$$

where r_1 and r_2 are random numbers, uniformly distributed within the interval [0,1]. ω is a parameter called the *inertia weight*, and c_1, c_2 are positive constants, referred to as *cognitive* and *social* parameters, respectively. The settings of ω, c_1, c_2 of the terms affect the performance of the PSO method. An alternative version of the PSO method is denoted in [7].

2. Proposed Method Based on DPSO

The DPSO method, which is a discrete binary version of the PSO method, is a promising method proposed for combination optimization problems, where the search process of the DPSO method complies with that of the PSO method [11]. In the DPSO method, each element of the position vector is transformed in {0,1} according to the following rule:

$$\text{if } \rho < sig(v_{id}^{k+1}) \quad \text{then} \quad x_{id}^{k+1} = 1; \qquad \text{else} \quad x_{id}^{k+1} = 0 \tag{2}$$

$$sig(v_{id}^{k+1}) = \frac{1}{1+\exp(-v_{id}^{k+1})} \tag{3}$$

where ρ is a quasirandom number selected from a uniform distribution in [0,1].

In this study, a general wireless sensor network consisting of static sensor nodes placed in an object area is assumed. At the initial stage of the network, the sink node set requests the topology information from every sensor node by broadcasting a Topology Discovery Message (TDM) to the network by using the original flooding. Each sensor node receiving the TDM sends a Topology Response Message (TRM) with the local topology information of the sensor node, such as the number of neighbor nodes and the list of neighbor node IDs, to the sink node. The sink node constructs the network topology information from the gathered TRMs. The proposed method searches multiple forwarding nodes sets based on the constructed network topology information.

By the repetitive searches based on the DSPO method, multiple forwarding nodes sets are computed. In order to detect different forwarding nodes sets, the following rule corresponding to the above (2) is introduced:

$$\text{if } \rho < sig(v_{id}^{k+1}) \times s_r \quad \text{then} \quad x_{id}^{k+1} = 1; \qquad \text{else} \quad x_{id}^{k+1} = 0 \tag{4}$$

where s_r is a constant determined in the interval [0,1], named the *suppression* parameter.

In the first search, the *suppression* parameter (s_r) is set to 1.0 and the search by the ordinary DPSO method is executed. On and after the second search, multiple forwarding nodes sets can be effectively computed by the *suppression* parameter (s_r) set in (0,1). In case that s_r is set to 0.0, perfectly different multiple forwarding nodes sets can be searched.

To detect the optimum forwarding nodes set for disseminating queries or event data to the whole nodes in a network, the objective function is set as follows:

$$\max. \quad f(n_{forward}, n_{receive}) = \frac{s^{-(n_{total} - n_{receive})}}{n_{forward}} \tag{5}$$

where $n_{receive}$ and $n_{forward}$ represent the number of nodes receiving data and the number of forwarding nodes selected, respectively. n_{total} is the number of the whole nodes in a network.

III. EXPERIMENTAL RESULTS

Through the experiments, the performance of the proposed method is investigated to verify its effectiveness. The conditions of simulation and the values on DPSO parameters, which were used in the experiments performed, are shown in Table 1, where the selected values on DPSO parameters are considered proper default values and they are used in the relevant literature on the DPSO method. In Figure 1, an optimum forwarding nodes set is shown, where static sensor nodes are randomly arranged in the set experimental area.

Table1. Conditions of simulations and settings on DPSO parameters

Simulation size	100*m*×100*m*
The number of sensor nodes	73
Range of radio wave	25*m*
The number of particle	30
Cognitive parameter c_1	2.1
Social parameter c_2	0.8
Inertia weight ω	1.0

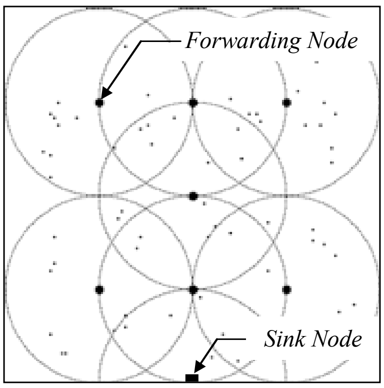
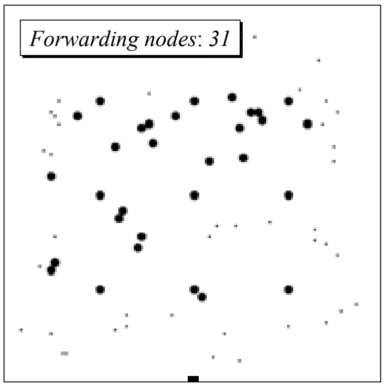
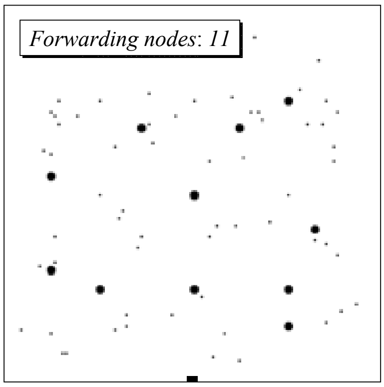


Fig.1. Simulation model

In the experimental results reported, the proposed method is evaluated through the comparison with the existing ones of [3,4] and based on Genetic Algorithm. On the method based on Genetic Algorithm, the parameter settings that were used in [4] and produced good results in a preliminary investigation were adopted for the comparison with the proposed method.



(a) Results by the method of [3]



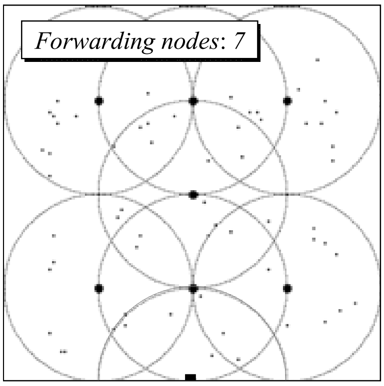
(b) Results by the method of [4]

Fig.2. Forwarding nodes set computed by using the methods of [3,4]

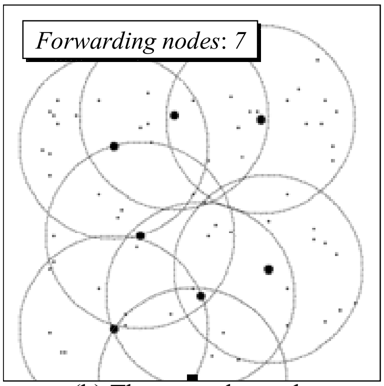
Table2. The number of selected forwarding nodes

	Greedy	*IUA*	*GA*	*Proposal*
The number of selected forwarding nodes	31	11	11	7

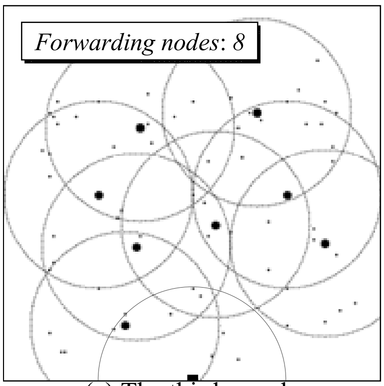
In Figure 2, a forwarding nodes set computed by using the methods of [3,4] is shown. The number of forwarding nodes selected by each method is reported in Table 2. In this table, two methods of [3] and [4] are denoted as *Greedy* and *IUA*, respectively. The method based on Genetic Algorithm is denoted as *GA*. The result on the proposed method is that obtained by the first search. From the results of Figure 2 and table 2, it is confirmed that the existing methods can not detect an optimum forwarding nodes set.



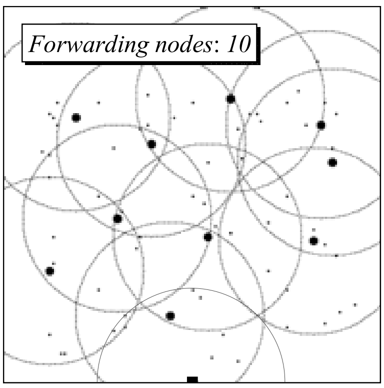
(a) The first search



(b) The second search

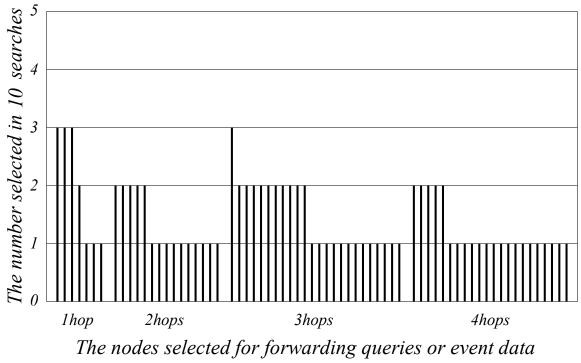


(c) The third search

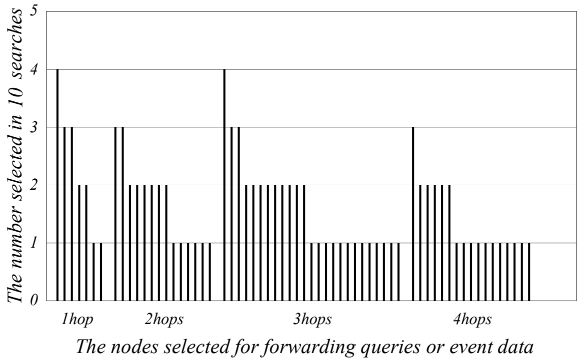


(d) The fourth search

Fig.3. Forwarding nodes computed by the proposal



(a) s_r = 0.2



(b) s_r = 0.4

Fig.4. The number selected as forwarding nodes in a total of 10 searches

Forwarding nodes sets computed by using the proposed method are illustrated in Figure 3. On the result of Figure 3, the *suppression* parameter (s_r) is set to 0.0. By the proposed method, perfectly different four forwarding nodes sets that include two optimum forwarding nodes sets are detected. The proposed method is a promising one selecting forwarding nodes for the dissemination of queries and event announcements. In Figure 4, the number selected in a total of 10 searches of the nodes selected for forwarding queries or event data by the proposed method are shown. From the result of Figure 4, it is considered that the nodes selected as forwarding ones are limited to some ones as the set value of the *suppression* parameter (s_r) is great.

IV. CONCLUSIONS

In this paper, a new efficient flooding method using discrete particle swarm optimization for the long-term operation of wireless sensor networks, which computes multiple forwarding nodes sets for disseminating queries and event announcements to the whole nodes in a wireless sensor network, has been proposed. Experimental results indicate that the proposed method has the development potential as an efficient flooding method for wireless sensor networks. In future studies, we want to execute the detailed evaluation on the parameter added to the proposed method, and on various network sizes and node density.

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