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A Study on Efficient Query Dissemination in Distributed Sensor Networks -Forwarding Power Adjustment of Each Sensor Node Using Particle Swarm Optimization-

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***Abstract*:** In a wireless sensor network, flooding is required for the dissemination of queries or event announcements. The original flooding causes the overlap problems. In the original flooding, generally, all sensor nodes receiving a broadcast message forward it to its neighbors by full forwarding power, resulting in a lot of collisions and duplicate messages. For a dense wireless sensor network, the impact caused by the original flooding may be overwhelming. The original flooding may result in the reduced network lifetime. Therefore, an efficient query dissemination method is needed to prolong the lifetime of a wireless sensor network. This paper proposes a new query dissemination method based on the particle swarm optimization method for the long-term operation of a wireless sensor network. 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*: Wireless Sensor Networks, Particle Swarm Optimization, Query Dissemination, Long-Term Operation.**

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. In a wireless sensor network, hundreds or thousands of micro sensor nodes, which are compact and inexpensive, are placed in a large scale observation area and sensing data 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. Therefore, the suppression of communication load is generally required for the long-term operation of a wireless sensor network.

In a wireless sensor network, flooding is required for the dissemination of queries or event announcements. The original flooding causes the overlap problems. In the original flooding, generally, all sensor nodes receiving a broadcast message forward it to its neighbors by full forwarding power, resulting in a lot of collisions and duplicate messages. For a dense wireless sensor network, 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 or event announcements has been studied to prolong the lifetime of a wireless sensor network. The existing methods of [1-4] have been proposed to resolve or improve the overlap problems of the original flooding in disseminating queries or event announcements in a wireless sensor network. However, the gossiping of [1] may result in some nodes not receiving queries. The existing methods of [2,3] can disseminate queries to the whole nodes construct a wireless sensor network, but can not select a most efficient and optimum forwarding nodes set. The method of [4] can compute an optimum forwarding nodes set, but a more efficient query dissemination method is needed to prolong the network lifetime.

This paper proposes a new query dissemination method based on the particle swarm optimization method for the long-term operation of a wireless sensor network. The rest of this paper is organized as follows. In Section II, the proposed method is described. In Section III, experimental results 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 study in Section IV.

II. PROPOSED METHOD

In this paper, an efficient query dissemination method based on the Particle Swarm Optimization (PSO) method, which adjusts the forwarding power of each node that constructs a wireless sensor network, is proposed. In this section, the PSO method is first outlined. Then, the proposed method based on the PSO method 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. 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

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

and the velocity vector

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

where the subscript i ($i = 1, \dots, N$) 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 position vector $\boldsymbol{gbest}$ of the best evaluation value among all particles 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 as follows (Fig.1):

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

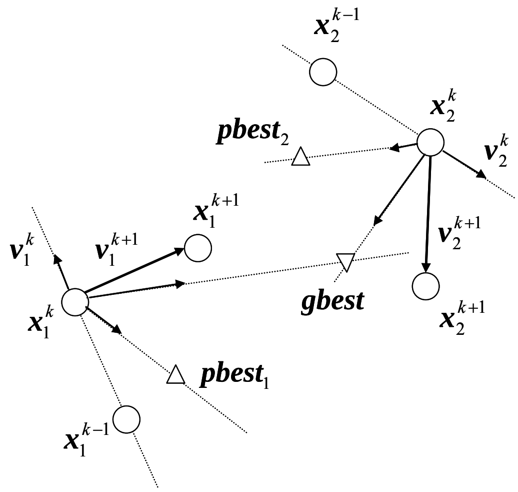


Fig.1. The movement of particles

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.

2. Proposed Method

In this study, a general wireless sensor network consisting of static sensor nodes with Global Positioning System (GPS) placed in an observation area is assumed. At the initial stage of the network, the sink node set requests the location information from every sensor node by broadcasting a Location Discovery Message. Each sensor node receiving this Location Discovery Message sends a Location Response Message to the sink node. The sink node can grasp the location information of each sensor node from the gathered Location Response Messages.

By applying the PSO method, this study detects an adjustment solution on the forwarding power of each sensor node that constructs a wireless sensor network based on the location information gathered by the sink node. In this study, variables are the forwarding power of each sensor node as follows:

$$\boldsymbol{x} = (E_T(1), E_T(2), \cdots, E_T(n_{total}))^\top \tag{2}$$

where $E_T(i)$ is the forwarding power of sensor node (i), and n_{total} represents the number of all sensor nodes that constructs a wireless sensor network.

To compute an adjustment solution on the forwarding power of each sensor node for disseminating queries or event announcements to all sensor nodes in a wireless sensor network and minimizing total energy consumption on forwarding of queries or event announcements, the objective function is set as follows:

$$f(\boldsymbol{x}) = \frac{s^{-(n_{total} - n_{receive})}}{\sum_{i=1}^{n} E_T(i)} \quad (3)$$

where $n_{receive}$ represents the number of sensor nodes that received queries or event announcements.

III. EXPERIMENTAL RESULTS

Through simulation experiments, the performance of the proposed method is investigated to verify its effectiveness. The conditions of simulation and the values on PSO parameters, which were used in the experiments performed, are shown in Table 1, where the selected values on PSO parameters are considered proper default values and they are used in the relevant literature on the PSO method. In Fig.2, an optimum forwarding nodes set is shown when range of radio wave of each sensor node is set to 25m, where static sensor nodes are randomly arranged in the set experimental area.

Table1. Condition of simulations and settings on PSO parameters

Simulation size	100*(m)*×100*(m)*
The number of sensor nodes	73
Range of radio wave	0 ~25*(m)*
The number of particle	30
Cognitive parameter c_1	2.1
Social parameter c_2	0.8
Inertia weight ω	1.0

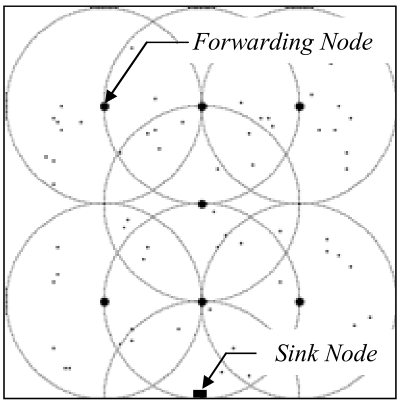
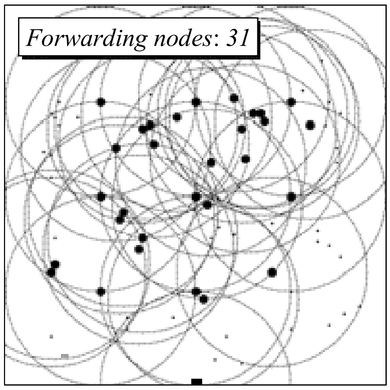
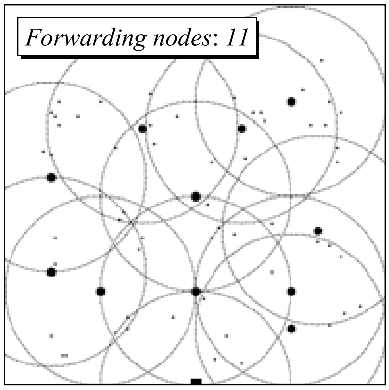


Fig.2. Simulation model

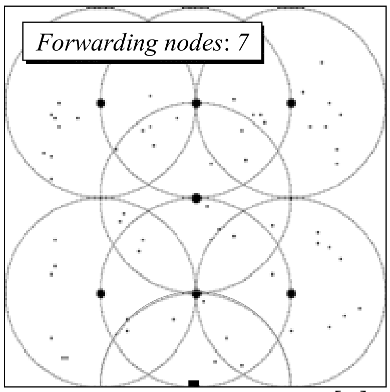
In experimental results reported, the proposed method is evaluated through the comparison with the existing ones of [2-4]. On the existing methods, range of radio wave of each sensor node was set to 25m, and the parameter settings that were used in [4] and produced good results in a preliminary investigation were adopted for the comparison with the proposed method. In Fig.3, a forwarding nodes set and the number of forwarding nodes selected by using the existing methods of [2-4] are shown. From the results of Fig.3, it is confirmed that the existing methods of [2,3] can not detect an optimum forwarding nodes set. The method of [4] computes an optimum forwarding nodes set, but a more efficient query dissemination method is required to prolong the lifetime of a wireless sensor network.



(a) Results by the method of [2]

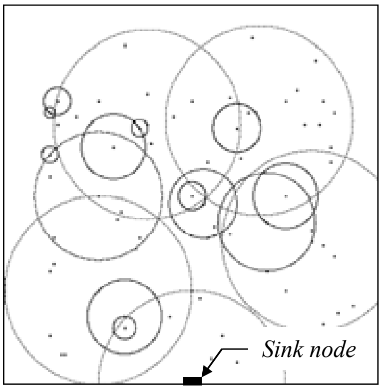


(b) Results by the method of [3]

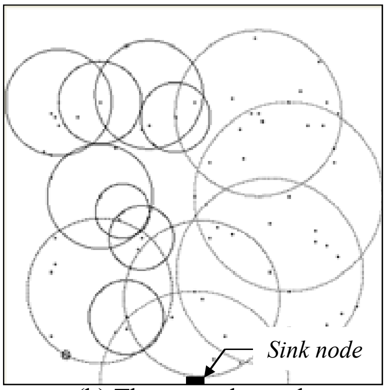


(c) Results by the method of [4]

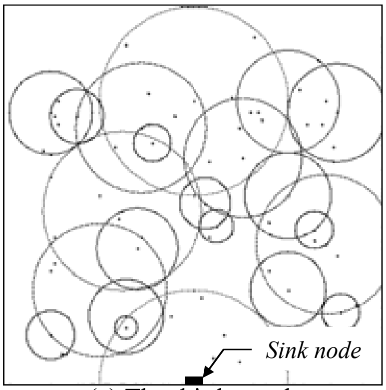
Fig.3. Forwarding nodes set computed by using the existing methods of [2-4]



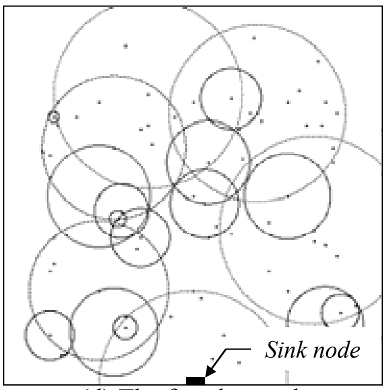
(a) The first search



(b) The second search



(c) The third search



(d) The fourth search

Fig.4. Results obtained by using the proposed method

Table2. Total energy consumption

		Total energy consumption
The method of [2]		100.6 μJ
The method of [3]		78.1 μJ
The method of [4]		73.6 μJ
Proposal (4searches)	Best value	71.7 μJ
	Mean value	72.2 μJ

Ranges of radio waves of all sensor nodes computed by using the proposed method are illustrated in Fig.4. In Table 2, total energy consumption on query disseminati-on of all sensor nodes that construct a network is shown. From Fig.4 and Table 2, it can be confirmed that the pr-oposed method is a promising query dissemination one for the long-term operation of wireless sensor networks.

IV. CONCLUSIONS

In this paper, an efficient query dissemination meth-od based on the PSO method for the long-term operati-on of a wireless sensor network, which adjusts the forw-arding power of each sensor node for disseminating qu-eries or event announcements to the whole nodes in a wireless sensor network, has been proposed. Experime-ntal results indicate that the proposed method has the d-evelopment potential as an efficient query dissemination one. In an actual sensor node, however, detailed adjust-ment of the forwarding power is difficult. In future stud-ies, we want to improve the proposed method by consi-dering actual sensor nodes.

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