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An Efficient Flooding Scheme in Wireless Sensor Networks Using Competitive PSO

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Abstract—Recently, Wireless Sensor Networks (WSNs) have been studied with a great amount of interests. In WSNs, 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 the full forwarding power, resulting in a lot of collisions and duplicate messages. For dense WSNs, the impact caused by the original flooding may be overwhelming. To realize long-term operation of WSNs, we discuss in this study a method of suppressing the communication load on sensor nodes by effective flooding. As a technique of forwarding power adjustment of each node for adaptive and efficient query dissemination, this paper proposes a method using a simple competitive PSO for finding plural acceptable solutions. The simulation results show that obtained solutions can contribute to flexible operation to WSNs.

1. Introduction

There is growing expectation for Wireless Sensor Networks (WSNs) as a means of realizing various applications, such as natural environmental monitoring and environmental control in residential spaces or factories[1]. In WSNs, hundreds or thousands of micro-sensor nodes are deployed in a large scale observation area and sensor information of each node is gathered to sink nodes by inter-node wireless 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, to realize long-term operation of WSNs, it is necessary to gather sensor information efficiently by saving node power consumption.

In WSNs, 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 their neighbors by the full forwarding power, resulting in a lot of collisions and duplicate messages. For dense WSNs, the impact caused by the original flooding may be overwhelming. So, the original flooding may result in the reduced network lifetime. However, in many cases of WSNs, all sensor nodes do not always have to forward reception message. As a method of solving this problem, the selecting methods of forwarding nodes (FNs) for the dissemination of queries or event announcements have been studied to prolong the lifetime of WSNs[2]-[3]. These studies assume that the forwarding nodes forward reception message by full forwarding power. However, in many cases of WSNs, each FN does not have to do it. To realize the effective flooding, a new query dissemination method based on the advanced Particle Swarm Optimization algorithm computing Plural Acceptable Solutions(PSO-PAS)[4], which detects plural acceptable solutions on the forwarding power of each sensor node, has been proposed[5]. Obtaining plural acceptable solutions can contribute to flexible operation to WSNs, and can operate WSNs effectively for a long time. However, PSO-PAS is sequential algorithm; deep search for each solution is difficult if the required number of solutions increases. In addition, PSO-PAS has many parameters and complicated processing. Therefore, the control of them is difficult.

We discuss in this study a method of forwarding power adjustment of each sensor node for adaptive and efficient query dissemination. This paper proposes a method using a simple Competitive PSO (CPSO)[6] as a more effective method. In CPSO plural acceptable solutions can be found by parallel processing and the control is easier. Through numerical simulations, we show that the proposed method can find plural candidates of FN sets for adaptive and efficient query dissemination.

2. Forwarding Node Selection in WSNs

In WSNs, sensor nodes and a sink node are set up in an observation area. Each sensor node has a specific radio range, and transmits sensor information to the sink node by multi-hop wireless communications between sensor nodes which exist within the radio range to each other. In WSNs, flooding is required for the dissemination of queries and event announcements. In the original flooding, each sensor node receiving a broadcast message forwards it to its neighbors, resulting in a lot of collisions and duplicate message. There have been methods to select Forwarding Nodes (FNs) to prolong lifetime of WSNs[2]-[3]. In these methods, as the selected FNs receive a broadcast message, the FNs forward it to their neighbors by full forwarding power. The other nodes only receive a broadcast message, and do not forward it. Also, by obtaining plural FN sets and switching them dynamically, load balancing of each sensor node can be realized. However, in many cases of WSNs, each FN does not have to forward reception message by the full forwarding power. Therefore, we discuss in this study a method of forwarding power adjustment of each node for adaptive and efficient query dissemination using CPSO[6].

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

3. Particle Swarm Optimization (PSO)

3.1. Original PSO

Particle Swarm Optimization (PSO) is a kind of metaheuristic algorithms emulating actions in swarms such as birds and fishes[7]. In PSO each particle has a velocity vector and a position vector. The velocity vector of a particle v_{t+1} is given by the following equation.

$$v_{t+1} = wv_t + c_1 \cdot rand \cdot (pbest_t - x_t) + c_2 \cdot rand \cdot (gbest_t - x_t) \quad (1)$$

where *pbest* is a personal best solution which each particle has, *gbest* is a global best solution which all particles have, v_t is a current velocity vector, *rand* is the uniform random numbers for [0,1], w is the inertia coefficient, and c_1 and c_2 are the weight coefficients. The position vector x_{t+1} of a particle is given by the following equation.

$$x_{t+1} = x_t + v_{t+1} \quad (2)$$

PSO can fast solve various optimization problems in nonlinear continuous functions, although the algorithm uses only simple and fundamental arithmetic operations. However, a basic PSO can find only a single solution for a single trial.

3.2. Advanced PSO for computing Plural Acceptable Solutions(PSO-PAS)

There has been a method of forwarding power adjustment in WSNs using advanced Particle Swarm Optimization algorithm computing Plural Acceptable Solutions (PSO-PAS,[4]) and the effectiveness has been discussed[5]. First, PSO-PAS search for a solution like PSO. In PSO-PAS, when the convergence of particles in the search process, however, the swarm is divided into particles for searching $gbest_1$ and ones for searching the other solution ($gbest_2$). According to the solution search status of each particle, PSO-PAS iterates this *specialization of role* until the desired number of acceptable solutions can be obtained.

In Ref.[5], it was shown that PSO-PAS was the most effective method in other effective flooding methods. However, PSO-PAS is sequential algorithm; deep search for each solution is difficult if the required number of acceptable increases. In addition, PSO-PAS has many parameters and complicated processing. Therefore, the control of them is difficult.

3.3. Proposed Method: Competitive PSO

In this paper, we propose a method for forwarding power adjustment using a simple Competitive PSO (CPSO,[6]) that can efficiently find plural different acceptable solutions by dividing particles into plural groups. In the original PSO, it is difficult to find plural solutions because all the particles search a single solution by moving toward global best solution. So, in the CPSO, it is considered that particles are divided into arbitrary *ng* groups. In addition, the k th group ($k = 1, 2, \cdots, ng$) has own local best solution ($lbest_k$) instead of global best solution as shown in Fig.1. As a result, plural solutions can be found because particles move toward each own $lbest_k$. Each group has a range in which the group search a solution preferentially. If a particle belonging to the kth group goes into the range of the other group, the particle is excepted from a candidate in updating $lbest_k$. Therefore, it is possible to search plural different solutions efficiently because each group does not go into the ranges of the other groups to each other. This range is referred to as priority search range r. When a group can not search any solutions by always overlapping the ranges of the other groups, this group can obtain no solution because its $lbest_k$ is reset at random every time. CPSO can effectively find desired plural acceptable solutions and can easily control them by adjusting a single parameter for the priority search range. Also, a group with the best priority can have almost the same solution quality to the original PSO. In addition, CPSO is not a sequential search method like general Tabu search[8] but a parallel search method by moving priority search regions dynamically. Therefore, CPSO can fast find plural solutions without repeating many trials.

4. Forwarding Power Adjustment

By applying PSO-PAS and CPSO, this study detects plural adjustment solutions on the forwarding power of each sensor node that constructs WSNs, based on the location information gathered by the sink node. In this study, the

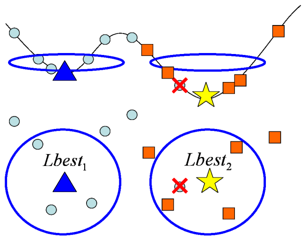


Figure 1: The priority search range

variable in the forwarding power of each sensor node is described as follows:

$$x = (E_t(1), E_t(2), \cdots, E_t(n_{total}))^T \quad (3)$$

where $E_t(i)$ is the forwarding power of sensor node i, and n_{total} represents the number of all sensor nodes that constructs WSN. The forwarding power of each sensor node is represented by an energy consumption model presented in Ref.[9]. To compute plural acceptable solutions on the forwarding power of each sensor node for disseminating query or event announcement to all sensor nodes in WSNs and to minimize total energy consumption on the WSN, the objective function is set as follows:

$$f(x) = \frac{S^{-(n_{total}-n_{receive})}}{\sum_{i=1}^{n} E_T(i)} \quad (4)$$

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

5. Experiment

Through numerical experiments, the performance of the proposed method is investigated. In order to confirm effectiveness of the proposed method, three methods, PSO, PSO-PAS, and CPSO, are applied to a forwarding power adjustment, and compare the solving performances. These are evaluated by the average values of the objective function (4) for 100 trials. The conditions in WSNs are shown in Table 1 and the parameters of the proposed method are shown in Table 2. The parameters of conventional method as shown in Ref[5]. Sensor nodes are randomly allocated in the observation area. Simulation model is shown in Fig.2. Also, one of optimum solutions in the case where the radio range of each sensor node is set to 150m is shown in this figure. This forwarding pattern is referred to as "Regular".

Forwarding patterns of all sensor nodes computed by using the proposed method are shown in Figs.3. In the figure, the circles represent the radio range. In Table 3, total energy consumption on query transmission of all sensor

Table 1: Conditions in WSNs

Parameter	value
Area Size	500(m) × 500(m)
Number of sensor node	100
Radio range	150(m)

Table 2: Parameters in proposed method

Parameter	value
Total number of iterations	4000
Inertia coefficient w	0.8
Weight coefficient c_1	2.0
Weight coefficient c_2	0.8
No. of group ng	3
Swarm's size p	ng ×30
Priority search range r	30
Weight parameter S	1.5

nodes that construct WSN is shown. Comparing the original PSO and CPSO for p = 90, quality of the 1st solution in the CPSO can be better than that in the original PSO. Also, in CPSO, parallel search in the solution space by groups of particles is possible. Therefore, two or more solutions can be obtained. Meanwhile, in PSO all the particles converge to a single solution and it is not possible to search other solutions. However, for p = 30 CPSO is worse than PSO. This means that swarm's sizes of each group in CPSO are not enough. In PSO-PAS, plural solutions are obtained by dividing the particles. However, as comparing qualities of total energy consumption, PSO-PAS is worse than PSO and CPSO. PSO-PAS is sequential algorithm; deep search for each solution is difficult if the required number of increases. In addition, PSO-PAS has many parameters and complicated processing. Therefore, the control of them is difficult. It causes insufficient search to each solution. On the other hand, qualities of total energy consumption in CPSO can be controlled easily by adjusting the parameter of the priority search region, and can be better than those in PSO-PAS. Therefore, CPSO can effectively find plural acceptable solutions and can easily control them. They are advantages of CPSO. Comparing the CPSO and PSO-PAS for p = 30, CPSO can obtain better solutions than PSO-PAS. This means that CPSO can search solutions more deeply than PSO-PAS. Therefore, the proposed method can operate WSNs more effectively for a long time than the conventional method.

Next, the results for changing priority search range r is shown in Table 4. Comparing the cases of r=30 and r=300, total energy consumption are almost the same. However, for r = 30, similar forwarding patterns between each solution can be found as shown in Fig.3. On the other hand, we have conformed that such similar patterns were not found for r = 300. When r increases, we can obtain of diversity solution patterns. But the range where plural acceptable

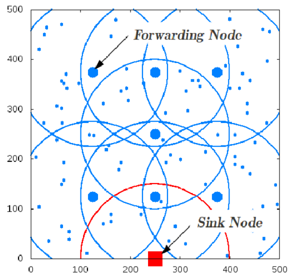
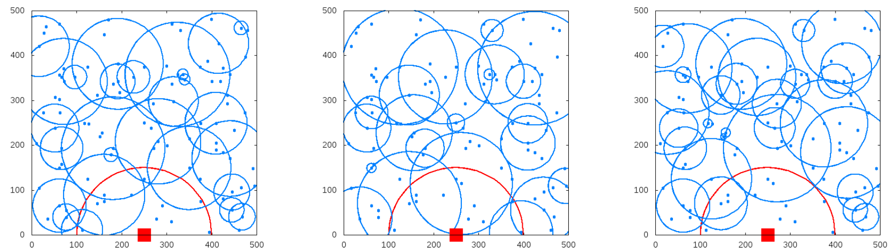


Figure 2: A simulation model and an optimum forwarding set



(a) 1st solution (b) 2nd solution (c) 3rd solution]

Figure 3: Forwarding patterns for CPSO (r = 30)

Table 3: Total energy consumption in each method(r=30)

	Obtained 3 solutions		
Method	1st	2nd	3rd
PSO(p=30)	3.149mJ	n/a	n/a
PSO(p=90)	3.115mJ	n/a	n/a
PSO-PAS(p=30)	3.405mJ	3.487mJ	3.561mJ
CPSO(p=90)	3.075mJ	3.210mJ	3.350mJ
CPSO(p=30)	3.208mJ	3.377mJ	3.536mJ
Regular	3.019mJ	n/a	n/a

Table 4: Total energy consumption in CPSO

	Obtained 3 solutions		
r	1st	2nd	3rd
30	3.075mJ	3.210mJ	3.350mJ
300	3.077mJ	3.211mJ	3.369mJ
400	3.099mJ	3.300mJ	3.619mJ

solutions can be found becomes narrow. Actually, in the case of r=400, the 3rd solution is much worse than other solutions.

Fig.4 shows a result of average radio range of each sensor node. The proposed method can suppress communication load on each sensor node, and can choose the better solutions with diversity. Therefore, the proposed method can contribute to flexible operation to WSNs, and can operate WSNs effectively for a long time.

6. Conclusions

We have discussed a method of forwarding power adjustment effectively to operate to Wireless Sensor Networks (WSNs) for a long time. For the effective search of forwarding power adjustment, this paper has proposed a method using a simple competitive PSO for finding plural acceptable solutions. For prolonging lifetime of WSNs, it is important to provide several candidates of forwarding node sets. In the simulation experiment, the effectiveness of the proposed method has been verified by comparing with the conventional methods.

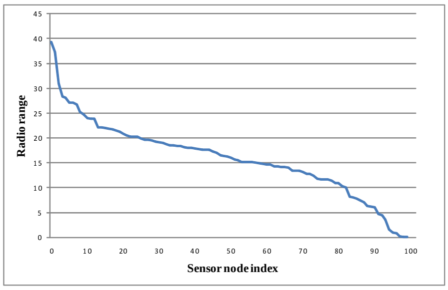


Figure 4: Average radio range (ng = 3, r = 300, p = 90)

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