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A Tabu Artificial Bee Colony Algorithm for Effective Forwarding Power Adjustment in Wireless Sensor Networks

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Abstract—This paper presents a method to find multiple forwarding power value sets for query dissemination in wireless sensor networks (WSNs). In WSNs, the query dissemination from a sink node to all wireless sensor nodes is required to control the wireless sensor nodes. In order to save total energy consumption in WSNs, it is needed that the number of forwarding nodes for the query dissemination and their forwarding power values are minimized. Also, in order to balance the loads of each wireless sensor node, multiple forwarding power value sets should be obtained. For the problem, a method to use a Tabu Artificial Bee Colony algorithm is proposed. As compared with the conventional methods, the proposed method is applicable to larger-scale WSNs. In the numerical simulations, the effectiveness of the proposed method is verified.

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. However, 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 methods based on the Competitive Particle Swarm Optimization(CPSO)[4] and the advanced Particle Swarm Optimization algorithm computing Plural Acceptable Solutions(PSO-PAS)[5], which detects plural acceptable solutions on the forwarding power of each sensor node, have been proposed. Obtaining plural acceptable solutions can contribute to flexible operation to WSNs, and can operate WSNs effectively for a long time[6]-[7]. However, in CPSO and PSO-PAS, it is difficult to search deeply for each solution if a large number of sensor nodes exist in WSNs. In recent years, the Artificial Bee Colony (ABC) method[8]-[10] which is effective for high-dimensional problems has been proposed. However, ABC can't find plural different acceptable solutions.

In this paper, we propose a method for forwarding power adjustment using the Tabu ABC (TABC) that can efficiently find plural different acceptable solutions. As compared with the conventional methods, the proposed method is applicable to larger-scale WSNs. In the numerical simulations, the effectiveness of the proposed method is verified.

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 the methods to select FNs to prolong lifetime of WSNs. 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, which is applicable to larger-scale WSNs.

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. Artificial Bee Colony (ABC)

3.1. Original ABC

The Artificial Bee Colony (ABC)[8]-[10] is a recently proposed metaheuristic algorithm that simulates the foraging behavior of a bee colony. In ABC algorithm, artificial bees explore the area around the food source (solution). A colony size is the total number of the employed bees and onlooker bees. The number of food sources is equal to the number of employed bees. The ABC algorithm consists of the following three phases.

(1) Employed Bees Phase

Each employed bee is associated to one of food sources and tries to renew the food source by the following equation.

$$v_{id}^k = x_{id}^k + \phi \cdot (x_{id}^k - x_{md}^k) \tag{1}$$

where v is a candidate point to be renewed, x is the position of the food source, i ($i = 1 \sim N$) and m ($m = 1 \sim N, m \neq i$) are the indexes of food sources, k is the number of iterations, ϕ is the uniform random numbers for $[-1, 1]$ and d ($d = 1 \sim D$) is the index of design variable selected by uniform random numbers. If an evaluation value of a selected candidate point is better than that of the food source, then the position of the food source is replaced to the candidate point. In addition, counter value s is updated as follows.

$$s_i = \begin{cases} s_i + 1 & if \quad f(v_i^k) \geq f(x_i^k) \\ 0 & if \quad f(v_i^k) < f(x_i^k) \end{cases} \tag{2}$$

where $f(\cdot)$ is an objective function to be minimized.

(2) Onlooker Bees Phase

The fitness (fit_i^k) of each food source (x_i^k) is calculated by the following equation.

$$fit_i^k = \begin{cases} \frac{1}{1+f(x_i^k)} & if \quad f(x_i^k) \geq 0 \\ 1 + abs(f(x_i^k)) & if \quad f(x_i^k) < 0 \end{cases} \tag{3}$$

It is used in computing the probability of the relative value of each food source (P_i^k) by the following equation.

$$P_i^k = \frac{fit_i^k}{\sum_{n=1}^{N} fit_n^k} \tag{4}$$

By Equation (1), onlooker bees will then search for a food source that is selected by roulette selection based on the probability P_i^k.

(3) Scout Phase

In the above search for a solution, if s_i is greater than or equal to the limit value lv, the food source (x_i) will be relocated at a random point within the search space.

3.2. Proposed Method: Tabu ABC

In this study, a new query dissemination method based on the Tabu Artificial Bee Colony(TABC), which can detect plural acceptable solutions, is proposed. In the original ABC, a food source in which the counter value achieves the limit value is relocated randomly by the scout. In order to obtain plural acceptable solutions, the location of such a food source is memorized before it is discarded. In TABC, the position of the food source with better objective function value is memorized. The other food source is relocated as same as the scout phase in the original ABC. However, there is a possibility that the same solutions are memorized. Therefore, the position of the Tabu range is created as shown in Fig.1. Thereafter, using the Particle Swarm Optimization (PSO[11]) within the Tabu range, local search is performed. Then the local optimum solution within the Tabu range is finally obtained by PSO. At that time, the Tabu range is also changed to the position obtained by PSO. If there are other food sources within the Tabu range, they are relocated randomly by the scout. In addition, if the candidate point of the food sources that contains within the Tabu range, it is not used in updating the position of the food source. Repeating in this manner TABC will be able to obtain plural solutions.

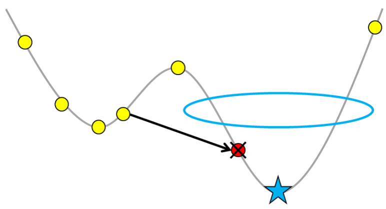


Figure 1: The Tabu range

4. Forwarding Power Adjustment

Using TABC and CPSO, plural adjustment solutions on the forwarding power of each sensor node are searched. In this study, the variable in the forwarding power of each sensor node is described as follows:

$$x = (E_T(d_1), E_T(d_2), \cdots, E_T(d_{n_{total}}))^T \tag{5}$$

where $E_T(d_i)$ is the forwarding power of sensor node i, d is the radio range, 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.[12]. To compute plural acceptable solutions on the forwarding power of each sensor node for disseminating query or event announcement to all sensor nodes in WSN and to minimize total energy consumption on the WSN, the objective function is designed as follows:

$$f(x) = \frac{S^{-(n_{total}-n_{receive})}}{\sum_{i=1}^{n} E_T(d_i)} \tag{6}$$

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

5. Experiment

5.1. Experiment Environment

Through numerical experiments, the performance of the proposed method is investigated. In order to confirm effectiveness of the proposed method, three methods, TABC, CPSO and ABC are applied to a forwarding power adjustment, and the solving performances are compared. These are evaluated by the average values of the objective function (6) for 10 trials. The conditions in WSNs are shown in Table 1 and the parameters of the proposed method are shown in Table 2. In the table, the parameters of the PSO for local search in the Tabu range is referring to Ref.[6]. The parameters of the original ABC are set to the same values as shown in Table 2. Also, the parameters of CPSO is referring to Ref.[6] and shown in Table 3. Sensor nodes are randomly deployed in the observation area. Simulation model for a WSN 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. In this case, total forwarding power value is 6.864mJ.

Table 1: Conditions in WSNs

Parameter	value
Area Size	$500(m) \times 500(m)$
Number of sensor node	400
Radio range	150(m)
Total number of iterations	30000
Weight parameter S	1.5
Tabu and priority search range r	400

Table 2: Parameters in proposed method

Parameter	value
Colony size cs	300
Employed bees eb	cs × 50%
Onlooker bees ob	cs × 50%
Limit value lv	4000
Top rate	0.05%
Iterations of the PSO search ips	1000
Inertia coefficient w	0.8
Weight coefficient c_1	2.0
Weight coefficient c_2	0.8
Swarm's size p	200

Table 3: Parameters in CPSO

Parameter	value
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	$ng \times 100$

5.2. Experimental Result

Forwarding patterns of all sensor nodes computed by using the proposed method are shown in Fig.3. In the figure, the circles represent the radio range. The average number of iterations in obtaining 3 solutions is 34035.8 + 1000 × 3. Table 4 shows total energy consumption on query transmission of all sensor nodes that construct WSN. TABC and ABC have better performances than the forwarding pattern shown in Fig.2. In TABC, it is possible to find plural acceptable solutions. Meanwhile, in ABC all the food sources converge to a single solution and it is not possible to search other solutions. Therefore, ABC will not be able to obtain plural forwarding patterns to prolong the lifetime of WSNs. Comparing TABC and CPSO, qualities of each solution in TABC can be better than those in CPSO. In addition, even if local search by PSO is not performed, TABC has better performance than CPSO. This means that TABC can search solutions more deeply than CPSO. This reason is why ABC has better performances for higher-dimensional problems than PSO[9]. In TABC, the basic search algorithm of ABC is not changed. Therefore, plural acceptable solutions can be obtained without losing the search performance of ABC. However, the location memorized by scout may not be the local optimal solution. Therefore, the PSO to explore the local optimal solution within the Tabu range can improve the qualities of each solution. As shown in Table 4, the TABC with PSO local search has the best performance in all the methods. Therefore, the proposed method can operate WSNs more effectively than the conventional methods. Figure 4 shows the average forwarding power of each sensor node in TABC with PSO local Search, CPSO and ABC. The figure shows that TABC can reduce the loads of each sensor node.

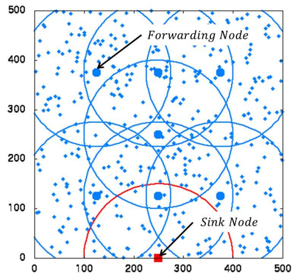
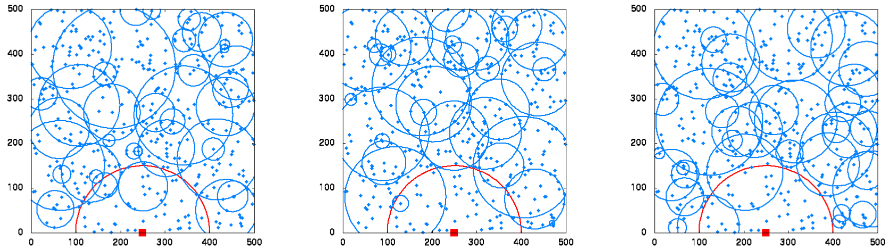


Figure 2: A simulation model



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

Figure 3: Forwarding patterns for TABC

Table 4: Total energy consumption in each method(r=300)

Method		*Totalenergyconsumption*		
		Best	*Ave.*	*Worst*
TABC with PSO local search	*Solution1*	6.186*mJ*	6.293*mJ*	6.385*mJ*
	Solution2	6.264*mJ*	6.353*mJ*	6.410*mJ*
	Solution3	6.371*mJ*	6.403*mJ*	6.461*mJ*
TABC without PSO local search	*Solution1*	6.217*mJ*	6.338*mJ*	6.449*mJ*
	Solution2	6.297*mJ*	6.401*mJ*	6.458*mJ*
	Solution3	6.396*mJ*	6.455*mJ*	6.513*mJ*
CPSO	*Solution1*	6.200*mJ*	6.456*mJ*	6.681*mJ*
	Solution2	6.344*mJ*	6.616*mJ*	6.796*mJ*
	Solution3	6.372*mJ*	6.797*mJ*	7.129*mJ*
ABC	*Solution1*	6.288*mJ*	6.336*mJ*	6.363*mJ*

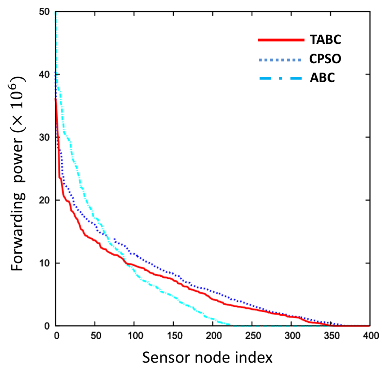


Figure 4: Average forwarding power of each sensor node

6. Conclusions

We have discussed a method of forwarding power adjustment effectively to operate to Wireless Sensor Networks (WSNs). For the effective search of forwarding power adjustment, this paper has proposed a method using a Tabu ABC 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 method. The results show that the proposed method can operate WSNs more effectively than the conventional methods.

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