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Ryohei Sato, Hidehiro Nakano, Arata Miyauchi

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A Power Optimization Method in Large-Scale Wireless Sensor Networks Using a Two-Stage Meta-Heuristic Algorithm

Ryohei Sato†, Hidehiro Nakano†, and Arata Miyauchi†

†Tokyo City University
1-28-1, Tamazutsumi, Setagaya-ku, Tokyo 158-8557, Japan
Email: {ryohei, nakano, miyauchi}@ic.cs.tcu.ac.jp

Abstract—In this paper, we propose a two-stage optimization method for the purpose of efficient flooding in wireless sensor networks. First, the forwarding node sets are selected by using a chaotic neural network. Then, the forwarding power values of each selected forwarding node are optimized by using an artificial bee colony algorithm. Using this method, it is possible to reduce the total energy consumption in the whole network, and to realize load balancing to each sensor node. In the numerical simulations, the effectiveness of the proposed method is verified.

1. Introduction

Recently, Wireless Sensor Network (WSNs) have been studied with a great amount of interests[1]-[3]. In WSNs, many sensor nodes are deployed in an observation area. Sensing data of each sensor node are transmitted to a sink node by multi-hop wireless communications. Then, the observation in large-scale area is possible. In general, each sensor node has only limited functions, and has a restriction in energy consumption. Therefore, it is necessary to control the communication loads in order to prolong the lifetime of WSNs.

The Fowarding Node Selection Problem (FNSP) is a problem that forwarding nodes for query messages from a sink node are effectively selected. For solving FNSP, a method to use a Chaotic Neural Network (CNN) has been proposed[4][5]. Also, the Forwarding Power Adjustment Problem (FPAP) is a problem that the forwarding power values in whole WSNs are reduced. For solving FPAP, a method to use a Tabu Artificial Bee Colony (TABC) algorithm which is an improved Artificial Bee Colony (ABC) algorithm in order to effectively obtain plural acceptable solutions has been proposed[9]. In the CNN method, all fowarding nodes forward reception messages by full fowarding power. On the other hand, in the TABC method, the load balancing to each sensor node is not sufficiently considered. In this paper, we propose a new method that combines a forwarding node selection method by CNN that can realize the load balancing to each sensor node, and a forwarding power adjustment method by ABC that can reduce the total energy consumption for selected forwarding nodes. In the numerical simulations, the effectiveness of the proposed method is verified.

2. Related works

2.1. Forwarding Node Selection Problem

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 messages. Collisions and duplicate messages consume large energy. Therefore, the selection of Forwarding Nodes (FNs) is needed to prolong the lifetime of WSNs. This problem is called the Forwarding Node Selection Problem (FNSP). As the selected FNs receive a broadcast message, the FNs forward it to their neighbors. The other nodes only receive the bloadcast message, and do not forward it. These nodes are reffered to as Receiving Nodes (RNs). In order to prolong the lifetime of WSNs, the number of FNs should be minimized with satisfying the constrained condition such that all the sensor nodes can receive broadcast messages. However, specific FNs are always selected, the FNs will consume large energy. Therefore, by obtaining plural FN sets and switching them dynamically, the load balancing to each sensor node can be realized. However, FNSP becomes high-dimensional combinational optimization problems if the number of sensor nodes increases.

For effectively solving FNSP, a method using a Chaotic Neural Network (CNN) which can obtain plural acceptable solutions in combinational optimization problems has been proposed[4][5]. In this method, it is possible to obtain a plural FN sets that can realize the load balancing to each sensor node. Using this method, the WSN lifetime can be prolonged. However, in the CNN method, all FNs forward reception messages by full fowarding power although they do not have to do it in many cases of WSNs.

2.2. Forwarding Power Adjustment Problem

In general, in forwarding broadcast messages, the energy consumption increases in accordance with the forwarding power. Therefore, it is important to adjust the forwarding power with selecting FNs. This problem is called the Forwarding Power Adjustment Problem (FPAP). In this problem, the total energy consumtion in whole WSNs can be reduced since each FN forwards broadcast messages by minimum forwarding power. In addition, by obtaining plural

FN sets and switching them dynamically, the loads concentrated to specific sensor nodes can be distributed to the other sensor nodes. However, FPAP becomes high-dimensional continuous optimization problems if the number of sensor nodes increases.

For high-dimensional continuous optimization problems, it is well known that the Artifical Bee Colony (ABC) algorithm is effective[6]-[8]. Therefore, to solve FPAP effectively, a method using a Tabu Artificial Bee Colony (TABC) algorithm which is an improved ABC algorithm in order to obtain plural acceptable solutions effectively in continuous optimization problems has been proposed[9]. In this method, it is possible to obtain plural FN sets in which each FN forwards broadcast messages by minimum forwarding power. However, in the TABC method, the load balancing to each sensor node is not sufficiently considered.

3. Proposed Method

In order to balance the loads to each sensor node and to reduce unnecessary forwarding power, we propose a method to combine a forwarding node selection method by CNN and a forwarding power adjustment method by ABC. A conceptual diagram of the proposed method is shown in Fig.1. As shown in Fig.1(a), in the selected FN sets, there are too large radio ranges in which no RN is present since each FN forwards broadcast messages by full forwarding power. Therefore, by adjusting forwarding power on the selected FNs, it is possible to reduce unnecessary forwarding power as shown in Fig.1(b).

The processing flow of the proposed method is shown below.

1. Executing CNN with constant iterations, FN sets are obtained in every iteration and they are memorized in an archive for candidate FN sets.

2. From the archive, one FN set is selected such that all FNs are not selected in the previously selected FN sets and the number of FNs is minimum, and the FN set is memorized in an archive for selected FN sets.

3. Return to 1 until the required number of the selected FN sets are obtained.

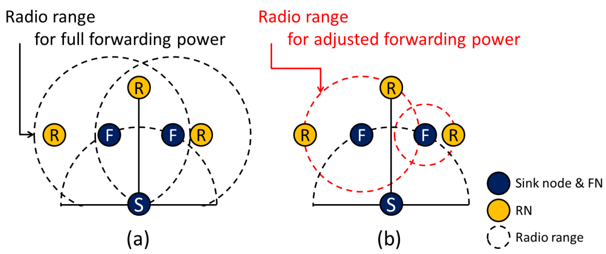

Figure 1: A conceptual diagram of the proposed method

4. For each FN set in the archive for selected FN sets, forwarding power adjustment is applied by using the ABC algorithm to satisfy the constraint condition such that all sensor nodes can receive broadcast messages. On the other hand, the forwarding power of each RN is set to 0.

Using the proposed method, it is possible to select the FNs to distribute the loads to each sensor node by CNN, and to reduce unnecessary forwarding power by ABC. Thus, the WSN lifetime can be prolonged.

In the proposed method, the forwarding power adjustment is applied only for the selected FNs obtained by CNN. Therefore, it is possible to significantly reduce the number of dimensions of search space in comparison with the case of adjusting forwarding power of all the sensor nodes. Therefore, the colony size and search iterations in ABC can be significantly reduced. The proposed method uses not the TABC algorithm but the ABC algorithm for forwarding power adjustment. Because, the plural FN sets can be obtained by CNN in advance, and the forwarding power adjustment is applied to each obtained FN set. The proposed method can find effective FN sets such that the loads to each sensor node are balanced and the total energy consumption in whole WSNs are reduced.

4. Experiment

In order to confirm effectiveness of the proposed method, the numerical experiments are performed. The three methods, the proposed method, the CNN method (forwarding node selection method by CNN) and the TABC method (forwarding power adjustment method by TABC) are applied to a WSN, and the performances are compared.

The number of sensor nodes, n, is 400, the requierd number of FN sets, m, is 20. The experimental results are shown as the average values for 10 trials. Fig.2 shows the simulation model of a WSN. The conditions in the WSN are shown in Table 1. The parameters of each method are shown in Tables 2 and 3, which are decided by referring the published papers and performing preliminary experiments. Sensor nodes are randomly deployed in the $500m \times 500m$ observation area. In Fig.2, one of optimum solutions in the case of FNSP is shown. The number of FNs is 7.

FN sets obtained by each method are shown in Fig.3. The radio ranges of all FNs are constant in the CNN method. Because, each FN obtained by the CNN method forwards broadcast messages by full forwarding power. The radio ranges of each FN are different in the TABC method. Because, the TABC method adjusts forwarding power of each sensor node. However, the number of FNs increases. In contrast, the number of FNs in the proposed method is as same as that in the CNN method and the radio ranges of each FN are adjusted.

Fig.4 shows total energy consumption in each sensor

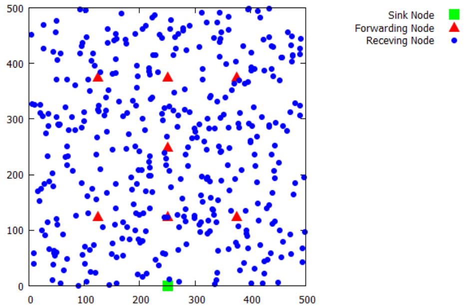

Figure 2: A simulation model

Table 1: Conditions in WSNs

Number of trials	10
Number of sensor nodes	400
Number of patterns of FN sets	20
Optimum solutions	7
Area size[m]	500×500
Sink node	(250, 0)
Radio range[m]	0∼150
$E_{elec}[nJ/bit]$	50
$k[byte]$	24
$\varepsilon_{amp}[pJ/bit/m^2]$	100
Weight parameter S	1.5

Table 2: Parameters in CNN

Number of iterations	1000
Exception range[m]	100
k_η, k_ζ	0.7
α	1.0
ε	0.02
C_ξ	0.08
C_η	0.01
C_ζ	50

Table 3: Parameters in ABC and TABC

Method	ABC	TABC
Number of iterations	1000	30000
Colony size	100	300
Limit value lv	50	4000
Tabu range	n/a	400
Iterations of the PSO search	n/a	1000
Inertia coefficient w	n/a	0.8
Weight coefficient c_1	n/a	2.0
Weight coefficient c_2	n/a	0.8
Swarm's size p	n/a	200

node E_i which is given by

$$E_i = \sum_{j=1}^{m} E_{ij} \quad (1)$$

where E_{ij} is the energy consumption of the ith sensor node in the jth FN set and m is the number of FN sets. The horizontal axis is the sorted sensor node index, and the vertical axis is the total energy consumption in each sensor node for 20 FN sets ($m = 20$). From the figure, the maximum value in the TABC method is 1.102 mJ. That is, the loads to specific sensor nodes are large. In contrast, the maximum value in the CNN method is 0.634 mJ. That is, the loads are distributed to each sensor node. This reason is why the TABC mehod does not sufficiently consider the load balancing to each sensor node, and the CNN method does not repeatedly select the same sensor nodes as FNs in each FN set. Since the maximum value in the proposal method is 0.634 mJ, the loads to each sensor node are distributed as well as the CNN method. In addition, total energy consumption in the whole WSN in the proposed method is less than that in the CNN method. This means that the combination of the forwarding node selection by CNN and the forwarding power adjustment by ABC can operate effectively.

Table 4 shows total energy consumption in the whole WSN E which is given by

$$E = \sum_{i=1}^{n} E_i \quad (2)$$

where n is the number of sensor nodes. From this table, the total energy consumption in the CNN method is larger than that in the TABC method. Because, the CNN method only selects FNs which forward broadcast messages by full forwarding power and the TABC method selects FNs and adjusts the forwarding power in order to reduce total energy consumption. The total energy consumption in the proposed method is smaller than that in the CNN method but a little larger than that in the TABC method. This reason is why the number of FNs is limited in order to realize the load balancing to each sensor node. However, the difference is not large.

From the mentioned above results, it can be said that the proposed method can distribute the loads to each sensor node and can reduce the total energy consumption in the whole WSN. Hence, the proposed method is more effective for prolonging the lifetime of WSNs.

5. Conclusion

In this study, we discussed a method of selecting effective forwarding node (FN) sets from among the sensor nodes placed in the observation area for the purpose of efficient flooding in wireless sensor networks (WSNs). As an effective search technique, we have proposed a method that uses the two optimization methods by using a chaotic neural network (CNN) and an artificial bee colony (ABC) algorithm. For prolonging the lifetime of WSNs, it is important to provide several candidates of FN sets. In the simulation experiments, the effectiveness of the proposed

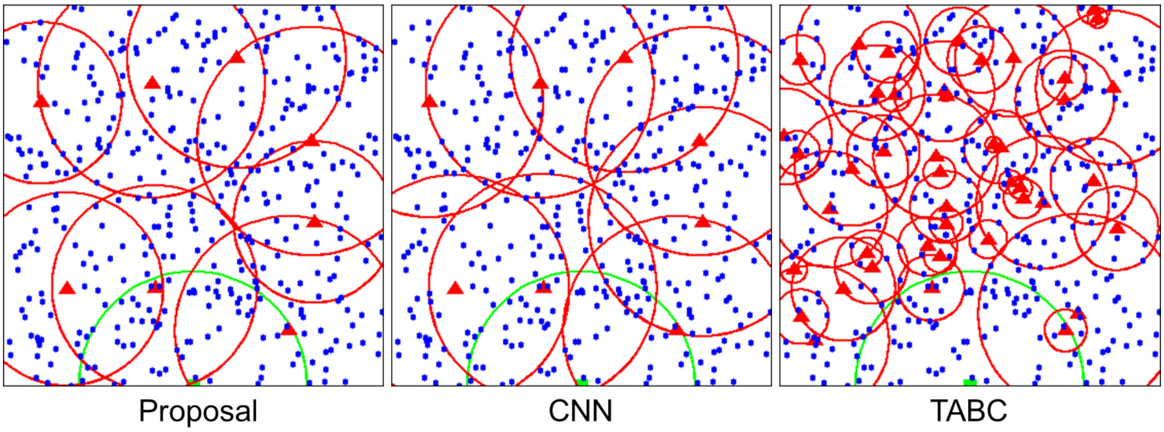

Figure 3: FN sets obtained by each method

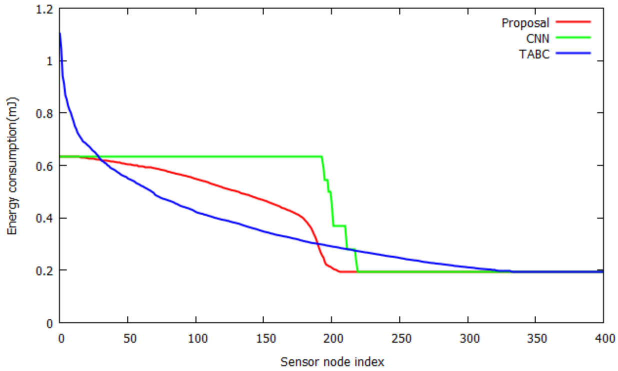

Figure 4: Energy consumption of each sensor node

Table 4: Total energy consumption in each method[mJ]

Method	Total energy consumption
Proposal	143.3
CNN	167.2
TABC	138.2

method has been verified by comparing with the conventional methods. The results show that the proposed method can operate WSNs more effectively than the conventional methods.

Future problems include comparison of the WSN lifetime in more detail, evaluation in the various sensor node deployments, and dynamic derivation of FN sets.

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