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A relay sensor node selection scheme in wireless sensor networks using a chaotic neural network

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Abstract—Recently, Wireless Sensor Networks (WSNs) have been studied with a great amount of interests. In WSN, 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. In this study, we use a Chaotic Neural Networks (CNN) to selection of forwarding nodes for the dissemination of queries and event announcements. We evaluate the applicability of CNN by computer simulations and discuss its development potential.

1. Introduction

Recently, Wireless Sensor Networks (WSNs) have been studied with a great amount of interests [1]-[4]. In WSN, many sensor nodes are set up in an observation area. Sensing information of each sensor node is transmitted to a sink node by multi-hop wireless communications. Then, the observation in the large-scale area is possible. In general, each sensor node has only the limited function, and has a restriction in energy consumption. Therefore, it is necessary to control the communication load in order to prolong lifetime of WSN. In WSN, 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 WSNs, the impact caused by the original flooding may be overwhelming. The original flooding may result in the reduced network lifetime. Therefore, the selection of forwarding nodes for the dissemination of queries and event announcements is needed to prolong the lifetime of WSNs. In many cases, all nodes do not have to broadcast, and it is possible to transmit information from a sink node to all nodes by appropriately selecting some Forwarding Nodes (FNs) . This problem is referred to as Forwarding Node Selection Problem (FNSP) . For the energy saving, the number of FNs should be minimized. However, if specific FNs are always selected, the FNs consume a lot of energy. Therefore, it is important to find plural solutions for FNSP and to switch them periodically. Then, the communication load of each sensor node is distributed. In our previous works, we have proposed a method for solving FNSP using a Chaotic Neural Network [5]. This method can search plural optimum selection patterns of FNs, efficiently [6]. This paper investigates performances of the method in detail in the viewpoints of long-term operation of WSNs. Some numerical simulation results are shown.

2. Forwarding Node Selection Problem (FNSP)

In this section, a problem named Forwarding Node Selection Problem (FNSP) in Wireless Sensor Networks (WSNs) is explained. In WSN, 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 WSN, 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. Therefore, the selection of Forwarding Nodes (FNs) is needed to prolong lifetime of WSN. As the selected FNs receive the broadcast messages, the FNs forward it to their neighbors. The other nodes only receive a broadcast message, and do not forward it. These nodes are referred to as Receiving Nodes (RNs). In order to prolong lifetime of WSN, the number of FNs should be minimized. However, the constrained conditions such that all the sensor nodes can receive broadcast messages should be satisfied. This problem is called FNSP. In FNSP, we assume that FNs are selected by a sink node. Therefore, the original flooding is assumed to be required only at first so that the sink node gathers location information of each sensor node. Fig. 1 illustrates an example of FNSP.

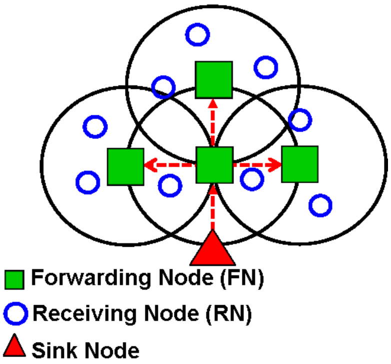

Figure 1: An example of FNSP

3. Conventional method

3.1. Chaotic Neural Network (CNN) for FNSP

In this section, a method for solving FNSP using a chaotic neural network (CNN) is explained [6]. First, a single sensor node is expressed by a single neuron. Each sensor node can directly communicate to the other sensor nodes within their radio range to each other. In this method, neurons corresponding to such sensor nodes are connected to each other. If a neuron fires, the neuron is regarded as FN. Otherwise, the neuron is regarded as RN. The model of CNN for FNSP is described by the following equations.

$$\xi_i(t+1) = k_\xi \xi_i(t) + C_\xi W_i \quad (1)$$

$$\eta_i(t+1) = k_\eta \eta_i(t) - C_\eta \sum_{j \in radio\_range} x_j(t) \quad (2)$$

$$\zeta_i(t+1) = k_\zeta \zeta_i(t) - \alpha x_i(t) + a \quad (3)$$

where ξ_i, η_i and ζ_i are internal states of the i th neuron for external input, mutual connection and refractoriness, respectively. W_i denotes the number of sensor nodes within radio range of the i th sensor nodes. x_j denotes the outputs of other neurons corresponding to sensor nodes within radio range of the i th sensor node, and x_i denotes the output of the i th neuron. The output of the i th neuron is described by the following equations.

$$x(t+1) = f\{y(t+1)\} \quad (4)$$

$$y_i(t+1) = \xi_i(t) + \eta_i(t) + \zeta_i(t) \quad (5)$$

$$f(x) = \frac{1}{1 + exp(\frac{-x}{\varepsilon})} \quad (6)$$

This model has 8 parameters: k_ξ, k_η, k_ζ, C_ξ, C_η, C_ζ, α, a, and ε.

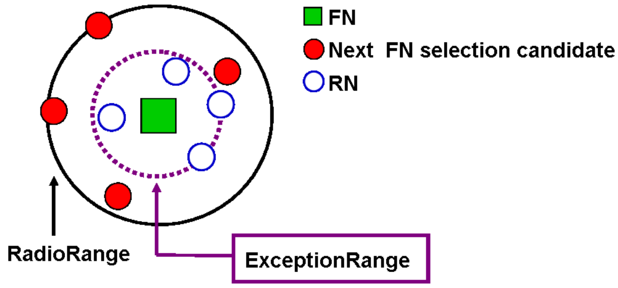

Figure 2: An example of exception range

3.2. Firing Decision Method (FDM)

After calculating all output values x_i, FNs are decided. However, it is difficult to always obtain executable solutions that satisfy the constrained condition. Then, the following Firing Decision Method (FDM) is introduced. First, let the sink node be FN, and let sensor nodes within radio range of the FN be RNs. Next, as shown in Fig.2, let an RN existing outside an exception range E_r and having maximum output in the RNs be a new FN. Repeating in this manner for decided FNs, a selection pattern of FNs is obtained at every iteration. Then, selection patterns are found in all iteration. The additional parameter E_r is important for the solving performance of FNSP. Especially, we focus on this parameter in this paper.

4. Purpose of this study

In our previous works a method to solve FNSP using CNN has been proposed as explained in Sec.3 [6]. However, consideration for the settings of appropriate parameters to target environments has not been sufficient so far. When the parameter E_r is large, a sensor node distant from presently decided FNs becomes a new FN in performing FDM. As a result, it causes a decrease of the number of FNs. However, FNs such that all sensor nodes can receive broadcast message might not be decided because the number of candidates of FNs decreases in performing FDM. That is, searching solution by FDM might not be success. When E_r is small, a sensor node near presently decided FNs tends to be selected as a new FN. Then, the total number of FNs can increase.
Moreover, in Ref.[6], only simulation results for uniform distribution WSNs have been presented. In actual use of WSNs, many sensor nodes are set up around a sink node because sensor nodes around the sink node consumes a lot of energy in relaying sensor information. It is necessary to realize the load-balancing of all the sensor nodes. This paper also considers solving performances in such a situation.

Table 1: Models of 4 kinds of WSNs

	number of nodes	
distribution	100	500
uniform	WSN1	WSN3
non-uniform	WSN2	WSN4

Table 2: Fixed settings of WSNs

Area size	50×50
Number of sensor nodes	500
radio range	20
sink node location	(15,15)

Table 3: Parameters for CNN

Iterations	2000
k_ξ, k_η, k_ζ	0.8
α	1.0
C_ξ	0.007
C_η	0.004
a	0.3
ε	0.02

5. Experiment

The purpose of FNSP is to minimize the number of FNs, and to obtain plural selection patterns of FNs. It is important to achieve long-term operation of WSN. The proposed method is applied to 4 kinds of WSNs as shown in Table 1, and other fixed settings are shown in Table 2. The solving performances for the parameters E_r are investigated by varying E_r from 0 to 20 (the size of radio range). The parameters in CNN are fixed as shown in Table 3. Fig.3 shows examples of locations of 500 sensor nodes. Fig.4 shows relations between E_r and the number of obtained FN selection patterns with search success rate. As shown in Fig.4, it can be confirmed that as E_r increases the search success rate decreases simultaneously, and the number of selection patterns increases. Fig.5 shows transitions of the number of FNs for a single trial. As shown in Fig 5, the obtained minimum number of FNs is 4 in this experiment. However, it can be confirmed that FNs more than 4 have been decided in many iterations. So, the selection patterns consisting more than 4 FNs are focused on and non-overlapping patterns to each other are extracted. Fig.6 shows an example of obtained FN selection patterns without overlapping. Fig.7 shows overwriting of these selection patterns. It can be confirmed that all selected FNs do not overlap to each other. The best size of E_r such that the most number of non-overlapping patterns can be obtained is different depending on WSN environments as shown in Table 4. In the table, the ratio of E_r to radio range is also shown. It is thought that it is impossible to decide appropriate value of E_r from these results. However, it was able to be confirmed that the size of E_r increased, too, as the number of FNs increased. Therefore, the size of E_r in case of number 100 of sensor can say that 88.5% is effective the size of ExceptionRange in case

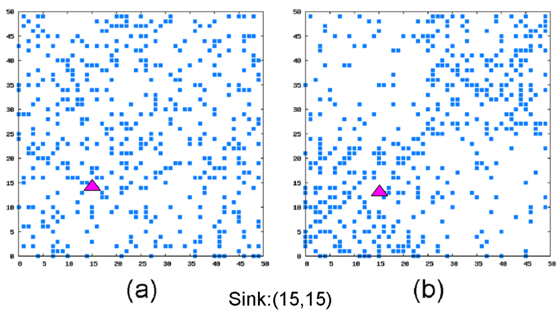

Figure 3: Examples of locations of 500 sensor node. (a) WSN3. (b) WSN4.

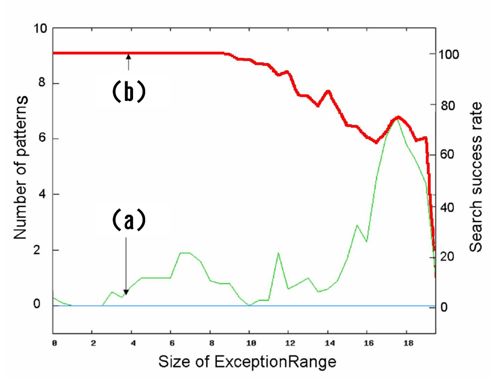

Figure 4: Relations between E_r and the number of FN selection patterns with search success rate (WSN3). (a) number of patterns. (b) search success rate.

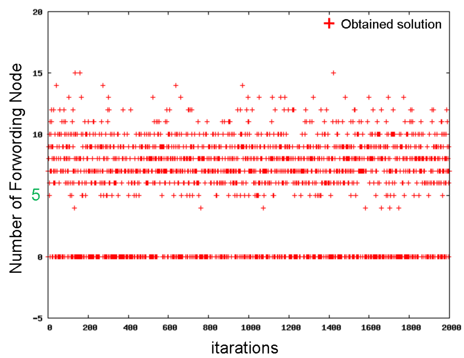

Figure 5: Transition of the number of FNs (WSN3).

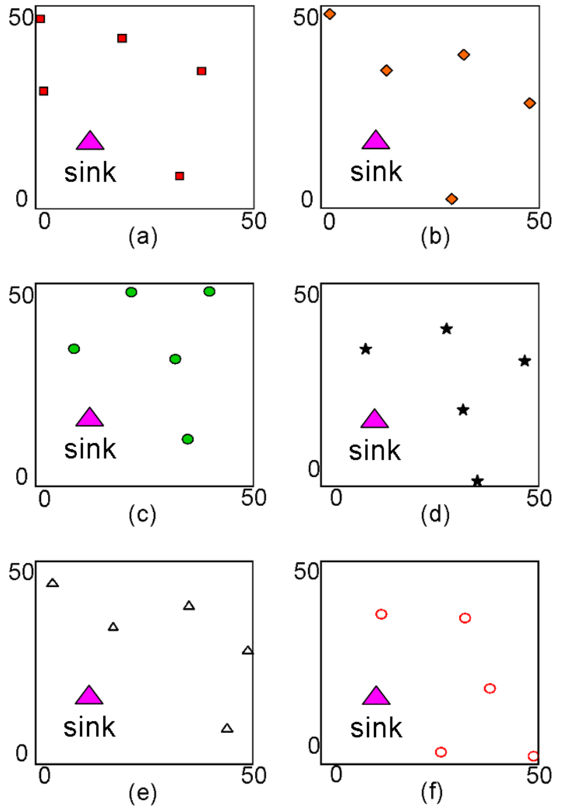

Figure 6: Example non-overlapping FN selection patterns (WSN3).

of number 500 of sensors by 76.0%. For dense WSNs, the value of E_r can be larger and a lot of selection patterns do not overlap to each other. However, too large values of E_r decreases search success rate. For the problem, we should consider improvement of the model of CNN and the algorithm of FDM.

6. Conclusions

We have presented a method for solving a forwarding node selection problem in wireless sensor networks using a chaotic neural network. In the simulation, solving performances for a parameter in deciding forwarding nodes have been analyzed in detail. This method can obtain a lot of effective selection patterns of the forwarding nodes depending on the parameter. Future problems include improvement of the model of CNN and the algorithm in deciding forwarding nodes, and analysis of lifetime of wireless sensor networks in using this method.

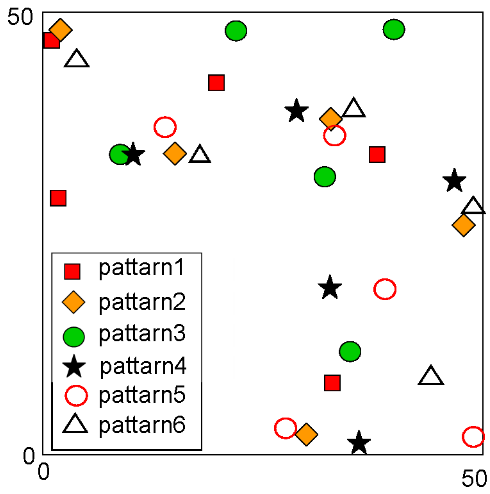

Figure 7: Overwriting of 6 FN selection patterns.

Table 4: Size of E_r in which the most number of non-overlapping patterns are obtained

WSN	E_r(%)	Average number of patterns
WSN1	16.0 (80.0)	7.3
WSN2	14.5 (72.5)	4.6
WSN3	17.5 (87.5)	6.8
WSN4	16.0 (80.0)	5.8

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