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An Efficient Flooding Scheme Using Chaotic Neural Networks in Wireless Sensor Networks

Tomoyuki Sasaki†, Hidehiro Nakano†, Akihide Utani†, Arata Miyauchi†, and Hisao Yamamoto†

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

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. 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 this study, we use the Chaotic Neural Networks (CNNs) 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]-[3]. 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 general, it is difficult to search the optimum solutions for FNSP by using simple algorithms. Moreover, as the target environment becomes larger and more complicated, it becomes much more difficult. In this paper, we propose a method to solve FNSP using a Chaotic Neural Network (CNN)[4]. CNN can search plural optimum solutions for FNSP effectively. We evaluate the applicability of CNN by computer simulations and discuss its development potential.

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 a broadcast message, 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 a broadcast message 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. Figure 1 illustrates an example of FNSP.

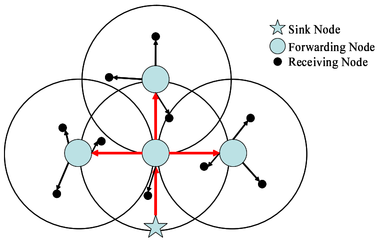


Figure 1: An Example of FNSP

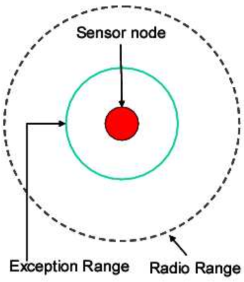


Figure 2: Exception range in firing decision method.

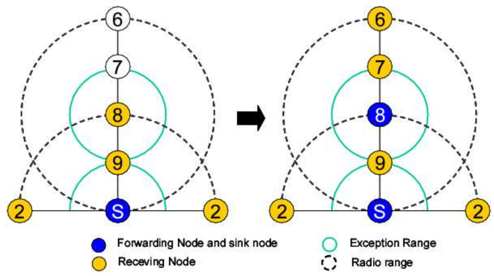


Figure 3: A procedure of Firing decision method.

3. Proposed Method

3.1. Chaotic Neural Network (CNN) for FNSP

We explain a method for solving FNSP using a chaotic neural network(CNN). First, a single sensor node is expressed by a single neuron. Each sensor node can directly communicate to the other sensor nodes within its radio range. In CNN, each neuron corresponding to such sensor nodes is connected to each other. If a neuron fires, the neuron is regarded as FN. If not, the neuron is regarded as RN. The model of CNN for FNSP is described by following equations.

$$\xi_i(t+1) = k_\xi \xi_i(t) + C_\xi * W_i \tag{1}$$

$$\eta_i(t+1) = k_\eta \eta_i(t) - C_\eta * \textstyle\sum_{k \in radio\_range} x_k(t) \tag{2}$$

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

where ξ_i, η_i and ζ_i are internal states of the i th neuron for external input, mutual connection and refractoriness, respectively.

In the external input term (1), W_i denotes the number of sensor nodes within the i th sensor node's radio range, and k_ξ and C_ξ are constant parameters. Generally, FNs should be selected so that they can directly communicate to more RNs. The external input term (1) evaluates such a sensor node.

In the mutual connection term (2), x_k denotes the outputs of other neurons corresponding to sensor nodes within the i th sensor node's radio range. And, k_η and C_η are constant parameters. In order to suppress total number of FNs, the i th sensor node should not be selected if many neighbor sensor nodes to the i th sensor node are selected as FNs. The mutual connection term (2) evaluates such a sensor node.

In the refractoriness term (3), k_ζ, α and a are constant parameters. If specific FNs are always selected, they consume a lot of energy. Therefore, plural solutions for FNSP should be found. The refractoriness term (3) controls chaotic search in CNN to find plural solutions.

The output of the i th neuron is described by the following equations.

$$x_i(t+1) = f\Big(\xi_i(t+1) + \eta_i(t+1) + \zeta_i(t+1)\Big) \tag{4}$$

$$f(y) = \frac{1}{1 + exp(\frac{-y}{\epsilon})} \tag{5}$$

3.2. Firing Decision Method

After calculating all output values x_k, FNs are decided. However, it is difficult to always obtain executable solutions that satisfy the constrained condition. Then, the following Firing Decision Method is introduced. First, let the sink node be FN, and let the sensor nodes within its radio range be RNs. Next, let the RN existing outside an exception range and having maximum output be FN. Figure 2 illustrates the exception range. Next, let all sensor nodes within all FN's radio range be RN. This procedure is repeated until all sensor nodes are decided as FN or RN. Figure 3 illustrates a procedure of firing decision method.

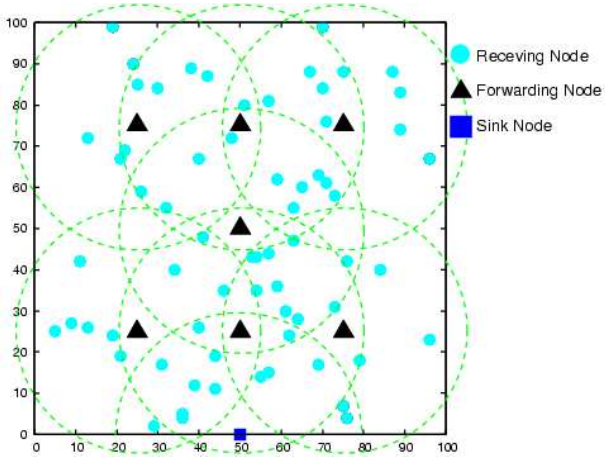


Figure 4: Sensor node allocations and one of optimum solutions.

Table 1: Simulation settings for FNSP

Simulation size	$100m \times 100m$
The number of sensor nodes	73
radio range	$30m$
sink node	$(50, 0)$

4. Experiment

In order to confirm effectively of the proposed method, we perform numerical experiments. Figure 4 shows allocations of sensor nodes. Table 1 shows simulation settings for FNSP. In Figure 4, one of optimum solutions for FNSP is presented. The number of FNs is 7. Table 2 shows parameters for CNN. Initial values of internal states for each neuron are decided as random values. Table 3 and Figure 5 show simulation results. For 1000 iterations, combinations of optimum FNs can be searched 21 times, and 20 different patterns can be found. Moreover, 3 different patterns such that all FNs do not overlap can be found as shown in Figure 6. These results show that the proposed method can select suitable FNs and can find plural combinations of FNs.

Figure 7 (a) shows the result for Greedy Algorithm. In the Greedy Algorithm, a sensor node is selected as FN if the sensor node has the most sensor nodes within its radio range, and this procedure is repeated. For the algorithm, the number of FNs is 46. Figure 7 (b) shows the result for Greedy Algorithm with exception range explained in Section 3. For the algorithm, the number of FNs is 8. These results show that it is difficult to find optimum solutions by using simple algorithms.

Table 2: Parameters for CNN

Iterations	1000
Exception range	21m
k_ξ, k_η, k_ζ	0.7
α	1.0
ϵ	0.02
C_ξ	0.02
C_η	0.01
a	0.02

Table 3: Simulation results

Number of times obtained optimum solutions	21
Number of optimum solution patterns	20
Number of non overlapped optimum patterns	3

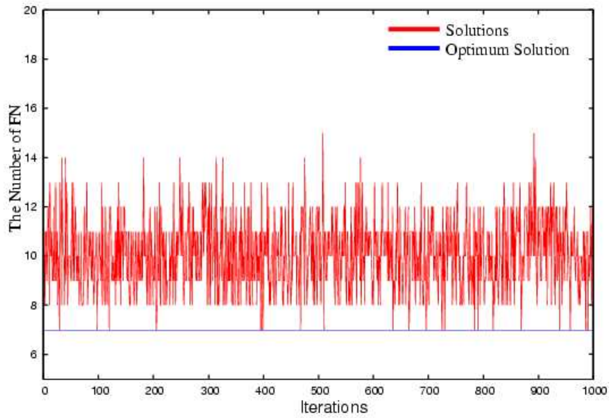
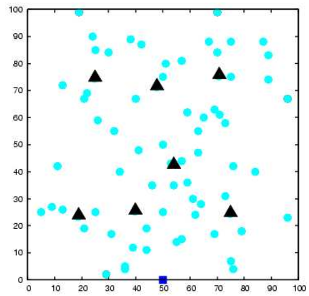
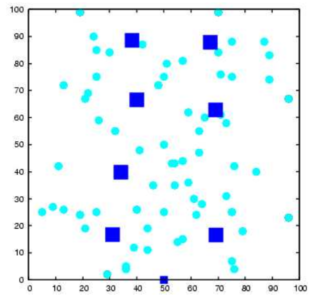


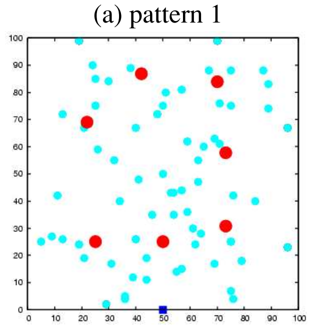
Figure 5: Transition of the number of FNs



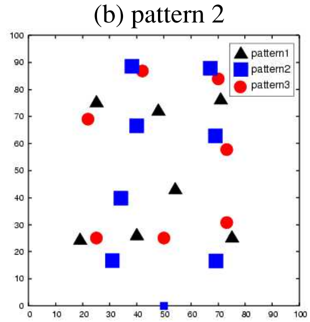
(a) pattern 1



(b) pattern 2

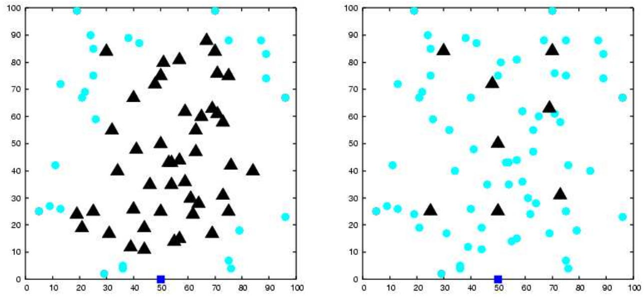


(c) pattern 3



(d) overwriting of three patterns

Figure 6: Solutions for FNSP



(a) (b)

Figure 7: Solutions for FNSP by Greedy Algorithm. (a) Greedy Algorithm. (b) Greedy Algorithm with exception range.

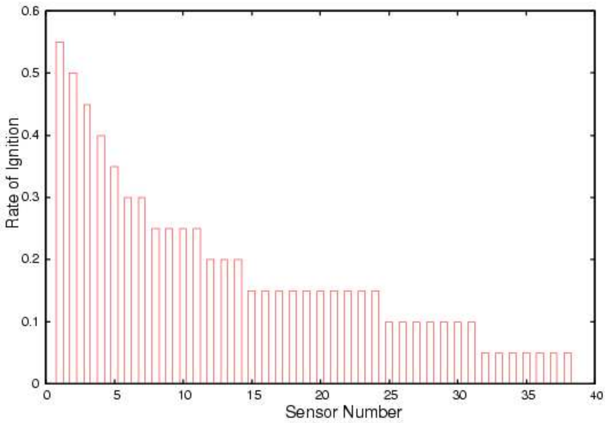


Figure 8: Firing Rate

In the simulation results, the number of FNs selected by the proposed method is less than that selected by two Greedy Algorithms. Moreover, the plural combinations of optimum FNs can be obtained by the proposed method. Therefore, proposed method is obviously more effective than Greedy Algorithm.

Next, we calculate firing rate of all sensor nodes for the obtained optimum solutions as shown in Figure 8. In the optimum solutions, the number of FNs is 7. However, many sensor nodes are selected as FNs for each optimum solution. This means that many different sensor nodes are selected for different solutions. This is an important result in the view points of load distribution and energy saving of each sensor node. If the plural combinations of FNs are switched periodically, the lifetime of WSN can be prolonged significantly.

5. Conclusion

In this paper, we have proposed a solving method for FNSP using CNN. The effectiveness of the proposed method have been verified by the simulation experiments. The method of Greedy Algorithm is a general idea. However, it is difficult to obtain optimum solutions. On the other hand, the proposed method can obtain plural optimum solutions. Therefore, proposed method is effective for prolonging lifetime of WSN.

Future problems include (1) application to larger WSN, (2) consideration for density of sensor nodes, and (3) evaluation for energy consumption.

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