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A solution strategy for packet routing problem by chaotic neurodynamics with degree information

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Abstract—Recently, because of the rapid spread of mobile devices, the number of flowing packets in the computer network increases, and this causes the congestion of the packets. As one of the effective packet routing methods to remove the packet congestion, a packet routing method using chaotic neurodynamics has already been proposed. By using the chaotic neurodynamics that realizes decentralized routings of packets, this method shows higher arrival rate of the packets than the shortest path routing. However, if the number of packets drastically increases, the method shows poor performance because packets are congested at the hub nodes. To remove the congestion at hub nodes, we proposed a new routing strategy using chaotic neurodynamics with degree information in this study. From results of the numerical simulations, the proposed routing method alleviates the packet congestion at the hub nodes effectively, achieving large number of packets are transmitted to their destinations in comparison to the conventional chaotic routing method and the shortest path routing.

1. Introduction

Recently, the Internet users continue to increase by rapid spread of convenient mobile devices. The number of flowing packets in the computer network then increases and this causes packet congestion. Therefore, an efficient packet routing method that alleviates the packet congestion is greatly desired. The shortest hop method (sp-hop method) that is commonly employed as the routing method in the communication networks [1] has serious problems; if the flowing packets in the network increases, the packet congestion occurs at the hub nodes. Thus, many packets are trapped at the hub nodes, and they spend long time to arrive at destinations. As one of the routing methods to remove the packet congestion at the hub nodes, a packet routing method using chaotic neurodynamics (chaotic method) has already been proposed [3]. By using the refractory effects which are included in chaotic neurons and can realize packet routing history, the routing method [3] avoids the packet congestion better than the sp-hop method. However, if the number of packets drastically increases, the method shows poor performance because some packets are congested at the hub nodes. We then proposed a new routing strategy for routings of packets by chaotic neurodynamics with degree information in this study. From the results of numerical simulations, the proposed routing method alleviates the packet congestion at the hub nodes effectively, achieving large number of packets are transmitted to their destinations in comparison to the conventional chaotic method and the sp-hop method. Also, by reducing the number of control parameters in the conventional chaotic method, the proposed routing strategy can apply to various topologies of the computer networks.

2. A computer network model

A network model used in this study is composed by nodes and links. Each node represents a router or a host and each link represents the connections between the nodes. It has been already reported that the Internet has scale-free property; a few nodes have many links and most of nodes have small links. Therefore, we employ the scale-free networks as topologies of the computer networks.

An example of degree distribution of the scale-free networks is shown in Fig. 1.

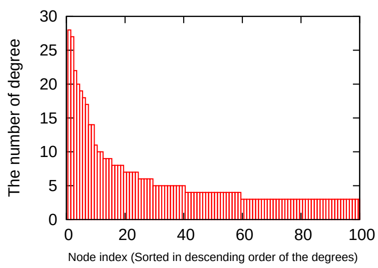


Figure 1: Degree distribution of the scale-free networks. We set the number of nodes to 100.

In Fig. 1, we can see that few nodes have large degree, and most of the nodes have small degree. In this study, we define the hub nodes as top four percent of the nodes sorted in the descending order of degrees. In each node, the packets are transmitted to an adjacent node using First-In First-Out (FIFO) principle. A single iteration is defined by the determinations of the transmitting nodes and the transmission to the nodes. Each node has transmission capacity C

that is the number of packet transmissions in the single iteration. In this study, we set C to 1. In addition, each node has buffer in which the packets are stored. In this study, we set the buffer size to infinity. We generated R packets whose generation and destination nodes are randomly determined using uniformly distributed random numbers at each iteration. Here, R is defined by $R = P_g \times N$, where P_g is a packet generating probability, N is the total number of nodes.

3. A packet routing method using chaotic neurodynamics

First, we describe how to realize the chaotic method [3]. We assume that the network has N nodes and the ith node $(i = 1, ..., N)$ has N_i adjacent nodes. Then, the ith node has a chaotic neural network which has N_i chaotic neurons.

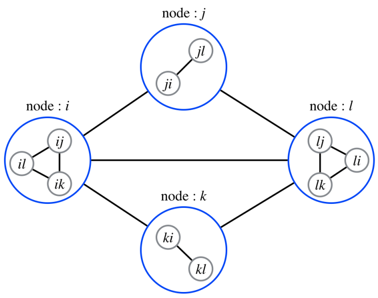


Figure 2: An example of the chaotic neural network.

In the chaotic method [3], the ijth neuron expresses connection between the ith node and the jth node. In addition, if the ijth neuron, the jth neuron in the ith chaotic neural network, fires, a packet is transmitted from the ith node to the jth adjacent node. Figure 2 shows an example of the chaotic neural network. To realize the packet transmission determined by the firing of neuron, we first assign the distance information to each chaotic neuron defined as follows:

$$\xi_{ij}(t+1) = \beta\left(1 - \frac{d_{ij} + d_{jg(p_i(t))}}{d_c}\right). \qquad (1)$$

In Eq. (1), $p_i(t)$ is a transmitting packet at the tth time, $g(p_i(t))$ is a destination node of $p_i(t)$, d_c is a network diameter, d_{ij} is the shortest hop from ith node to the jth adjacent node, $d_{jg(p_i(t))}$ is the shortest hop from the jth adjacent node to the $g(p_i(t))$, $\beta > 0$ is the control parameter. An example of the distance information from the ith node to the other nodes is shown in Fig. 3.

In Eq. (1), if the jth is the closest to the destination of the transmitting packet from the ith node, $\xi_{ij}(t+1)$ takes a maximum value. Therefore, we can realize the sp-hop method by using the distance information.

If the packet routing is carried out using the sp-hop method, the packets are trapped at the hub nodes because the computer network has the scale-free property. To avoid

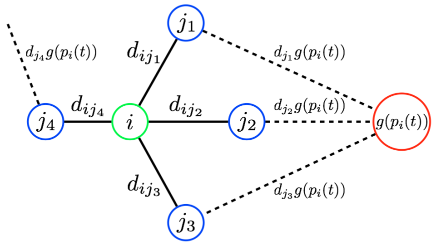


Figure 3: Distance information from the ith node.

such undesirable situation, we employ the following strategy; each node stores packet transmission history, then, a node to which the packet has been transmitted is hard to be selected as the transmitting node for a while. In order to realize this strategy, we next implement a refractory effect to each chaotic neuron. The refractory effect is one of the important characteristics of a real nerve membrane. If a neuron fires, it cannot fire for a certain temporal period. The refractory effect, $\zeta_{ij}(t+1)$, is defined as follows:

$$\zeta_{ij}(t+1) = -\alpha \sum_{s=0}^{t} k x_{ij}(t-s) + \theta. \qquad (2)$$

In Eq. (2), $\alpha > 0$ is the control parameter, $0 < k < 1$ is decay parameter, θ is the threshold. We next implement the mutual connection to each chaotic neuron, achieving controlling of the firing rate of neurons. The mutual connection, $\eta_{ij}(t+1)$, is defined as follows:

$$\eta_{ij}(t+1) = W - W \sum_{j=1}^{N_i} x_{ij}(t). \qquad (3)$$

In Eq. (3), $W > 0$ is the control parameter, N_i is the number of adjacent nodes of the ith node. In Eq. (3), if many neurons fire, the value of the second term in the right hand side of Eq. (3) increases. Finally, the output of the ijth neuron is defined as follows:

$$x_{ij}(t+1) = f\{\xi_{ij}(t+1) + \zeta_{ij}(t+1) + \eta_{ij}(t+1)\}, \qquad (4)$$

where f represents the sigmoid function that is defined as follows:

$$f(y) = \frac{1}{(1 + e^{\frac{-y}{\varepsilon}})}. \qquad (5)$$

In Eq. (4), if $x_{ij}(t+1)$ is larger than 1/2, the ijth neuron fires, and the packet is transmitted from the ith node to the jth adjacent node. If multiple neurons fire, we set a neuron that has maximum internal state fires.

By using Eq. (2), if the ijth neuron has fired past s steps, $x_{ij}(t-s)$ takes a positive value, then $\zeta_{ij}(t+1)$ takes a negative value. Therefore, the firing of the ijth neuron is suppressed at the tth time, and the packet is hardly transmitted to the jth adjacent node.

We evaluate the performance of the sp-hop method and chaotic method [3]. We repeated packet transmission for $T = 2000$. The distance between the nodes is set to 1. We set the parameters in Eqs. (1), (2), (3) and (5) as follow; $\beta = 1.2$, $\alpha = 0.045$, $k = 0.98$, $\theta = 0.5$, $W = 0.05$ and $\varepsilon = 0.5$.

In these simulations, we used the packet congestion rate and the average number of receiving packets as evaluation indices for routing methods. The packet congestion rate represents degree of congestion in the network. The packet congestion rate is defined as follows:

$$\gamma = \frac{C}{R}\frac{\sum_{t=1}^{T}(h(t) - h(t-1))}{T}, \quad (6)$$

where C is transmission capacity at every node, R is the number of generating packets at each iteration, $h(t)$ is the number of packets in the network at the tth iteration.

The network is congested if the packet congestion is close to 1. The packet congestion rate and the average number of receiving packets by the sp-hop method and chaotic method are shown in Figs. 4 and 5.

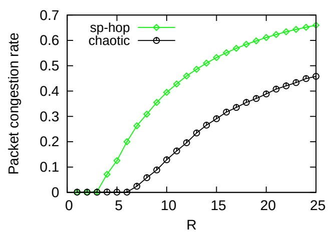
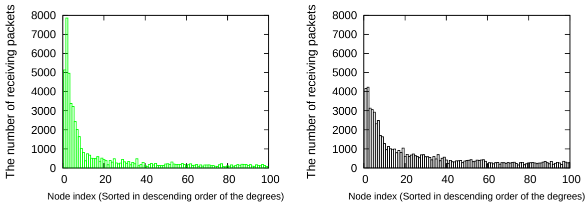


Figure 4: Packet congestion rate by the sp-hop method and the chaotic method.

In Fig. 4, although the packet congestion rate by the sp-hop method starts increasing when R becomes 4, that by the proposed method start increasing at $R = 7$. From this result, the chaotic method can avoid congestion in comparison to the sp-hop method.



(a) The sp-hop method (b) The chaotic method

Figure 5: Average number of receiving packets by (a) the sp-hop method and (b) the chaotic method ($R = 15$).

In Fig. 5, the chaotic method has smaller number of receiving packets at the hub nodes than the sp-hop method. However, even if the chaotic method can remove the packet congestion at hub nodes, many packets are still trapped at these hub nodes. We then expect that the performance of the chaotic method will be enhanced if the packets trapping at hub nodes are successfully avoided. We then propose the routing strategy for routing packets using chaotic neurodynamics with degree information in the next section.

4. A routing strategy using chaotic neurodynamics with degree information

From the previous results, we clarified that the chaotic method cannot remove the congestion at the hub nodes, if the number of packets increases. In order to improve this problem, we change the distance information as follows:

$$\xi_{ij}(t+1) = 1 - \frac{d'_{ij} + d'_{jg(p_i(t))}}{\sum_{j=1}^{N_i}(d'_{ij} + d'_{jg(p_i(t))})}. \quad (7)$$

In Eq. (7), d'_{ij} is the shortest path length using degree information from the ith node to the jth adjacent node, $d'_{jg}(p_i(t))$ is the shortest path length from the jth adjacent node to the $g(p_i(t))$. In Eq. (7), distance from the ith node to the jth node is determined using the degree of the jth node. Conversely, the distance from the jth node to the ith node is determined by the degree of the ith node (Fig. 6). By using the degree information as the distance between the nodes, we expect that the packets are hardly to be transmitted to the hub nodes.

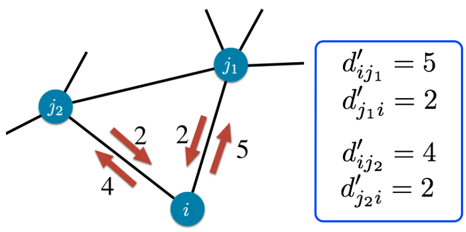


Figure 6: Distance between the nodes using degree information.

The chaotic method [3] uses a control parameter $\beta > 0$, but our proposed method remove this parameter by regarding β as 1. We also change d_c used in Eq. (1) to the sum of the path lengths among the adjacent nodes because Eq. (1) has the possibility to take a negative value if the distance from the adjacent node is larger than the network diameter. By implementing Eq. (7) only, and we set the jth node which has maximum value among all the adjacent nodes as the transmitting node, we can realize a sp-degree routing method. Next, we introduce the refractory effect defined by Eq. (2) to the ijth neuron. As compared to the chaotic method [3], functionality of the refractory effect is completely different. Although the packets are easily to be transmitted to the nodes which have small degree using Eq. (7), the packet can be transmitted to the hub nodes using the refractory effect in this method. Equation (8) represents a modified the mutual connection.

$$\eta_{ij}(t+1) = \frac{1}{\sum_{j=1}^{N_i} x_{ij}(t)}. \tag{8}$$

The chaotic method [3] uses a control parameter $W > 0$, but our proposed method removed this parameter. Finally, we determine the output of the ijth neuron in the same way used by the chaotic method [3].

We evaluate the performance of the proposed method using the sp-hop method, chaotic method and sp-degree method. Experimental conditions are the same as those used in the Section 3.

Parameters of the proposed method were set to $\alpha = 2.2\times 10^{-4}$, $k = 0.99$. The packet congestion rates for the scale-free networks by the routing methods are shown in Fig. 7.

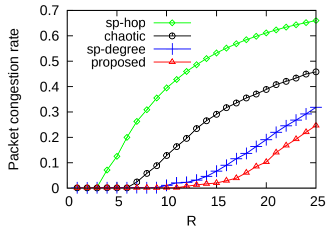
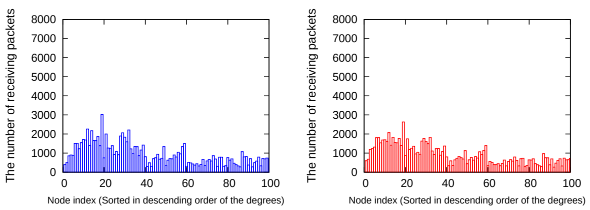


Figure 7: Packet congestion rates by the routing methods.

In Fig. 7, the proposed method shows smaller congestion rate than the other routing methods. Figure 8 shows the average number of receiving packets by the sp-degree method and our proposed method.



(a) sp-degree method (b) proposed method

Figure 8: Average number of receiving packets of (a) sp-degree and (b) proposed methods ($R = 15$).

In Fig. 8, the sp-degree method and the proposed method decentralize the packets at the hub nodes compared with that by the sp-hop and the chaotic methods (Fig. 5). In addition, the proposed method can remove the packets at the hub nodes in comparison to the sp-degree method.

Finally, we investigate the average difference of the number of receiving packets by the sp-degree method and the proposed method. Figure 9 shows the average difference of receiving packets by the sp-degree and the proposed methods.

In these simulations, we changed the distributions for generation packets for 20 times and averaged the results. In addition, we set R to 15. In Fig. 9, the nodes in the proposed method receive more packets than the ones in the sp-degree method if the value is positive. Conversely, the nodes in the sp-degree method receive more packets than the proposed method if the value is negative. From Fig. 9, the proposed method can use hub nodes to transmit the packets in comparison to the sp-degree method. These transmissions can diverse the path selections for routing the packets realized by the chaotic neurodynamics, resulting in alleviating packet congestion.

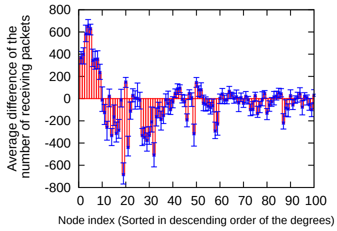


Figure 9: Average difference of receiving packets by the sp-degree method and the proposed method ($R = 15$).

5. Summary

In this study, the packet routing method using chaotic neurodynamics method with degree information is proposed to remove the packet congestion at hub nodes. From the numerical experiments, the proposed method removes the packet congestion by diversifying the packet transmissions using low-degree nodes. Furthermore, we remove some parameters used in the conventional chaotic routing method, achieving easy setting of optimum values for effective routings. In future works, the performance evaluation by changing packet generating distribution and the transmission capacity of the each node will be conducted the research of T.K. was partially supported by a Grant-in-Aid for Young Scientists (B) from JSPS (No.16K21327).

References

[1] E. W. Dijkstra, "A note on two problems in connexion with graphs," *Numerical Mathmatics*, Vol. 1, pp. 269–271, 1959.

[2] A. -L. Barabási and R. Albert, "Emergence of scaling in random networks," *Science*, Vol. 286, pp. 509–512, 1999.

[3] T. Kimura and T. Ikeguchi, "An optimum strategy for dynamic and stochastic packet routing problems by chaotic neurodynamics," *Integrated Computer-Aided Engineering*, Vol. 14, pp. 307–422, 2007.

[4] A. Arenas et al., "Communication in Networks with Hierarchical Branching," *Physical Review Letters*, Vol. 86, pp. 3196–3199, 2001.