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Traffic Dynamics on Effective Routing Strategy for Complex Networks

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Abstract—
To establish reliable communication between end users, alleviation of the congestion of packets in the communication networks is the most important problem. As one of the effective routing methods for reliable communication, we have proposed a routing method with chaotic neurodynamics, and another routing method with memory information. For recent works on the routing packets, a packet generating rate is used to evaluate the routing method for the communication networks. Thus, we evaluate the effectiveness of the routing method with the memory information using the packet generating rate in this paper. By using memory information effectively, packets are spread into the communication networks, achieving a higher performance than the conventional routing method for the complex network topology.

1. Introduction

To improve the capability of the communication network in carrying a large volume of data traffic, we need effective routing methods which can reduce drastically the congestion of the communication network. Recent works in the development of routing methods have evolved along two basic ideas. The first one is the selection of paths for transmitting packets based on only local information of the communication network such as degree information [1]. The second idea is to utilize global information such as the shortest distance information of the communication network. Yan et al.[2] proposed a routing method using both the distance information and the degree information. Kimura et al. proposed a routing method using neural networks with stochastic effects[3].

To alleviate the packet congestion, one of the possible methods is to prohibit the transmission of the packets to an adjacent node to which the packets just have been transmitted for a while. From this view point, a routing method with chaotic neurodynamics is proposed in [4, 5, 6]. In the chaotic routing method[4, 5, 6], a refractory effect, which is an important characteristic in nerve membrane[7] and produces the chaotic neurodynamics plays a key role: it memorizes a past routing history. Using the refractory effect or the past routing history, the chaotic routing method shows high performance for several types of complex networks such as the randomized networks[3], the small-world networks[8], and the scale-free networks[9]. In addition, based on the idea of the past routing history, a routing method with memory information is proposed[10]. Then, the routing method with memory information is evaluated by the model of the computer networks in which the fixed number of packets is flowing[10]. However, for recent works on the routing of the packets[11, 12], an order parameter is used to evaluate the performance of the routing method. For example, a packet generation rate is introduced to clarify the phase transition point between the free-flow state and the congested state[11, 12]. Then, in this paper, we evaluate the routing method with memory information for the computer networks in which the packet generation rate is introduced. Obtained results indicate that the packet routing history is very effective for the routing of the packets. In addition, the routing method with the memory information[10] shows the similar performance as compared to the routing method in which the waiting time of the adjacent nodes is incorporated[11, 12].

2. Communication network model

We take an unweighted and undirected graph $G = (V, E)$ as the network model, where V is the set of nodes and E is the set of links. Each node represents a host and a router in the network, and each link represents a physical connection between two nodes. All the packets are transmitted to their destinations according to the first-in-first-out principle. Sources and destinations of the packets are randomly selected using uniformly distributed random numbers. To construct the communication networks, we assign to each node a processing capability, C_i. The processing capability of the ith node is defined by $C_i = 1 + \lambda B_i$, where $0 < \lambda \leq 1$ is a controlling parameter. The processing capability corresponds to the the maximum number of transmitting packets at a time. In this paper, we set λ to 1.0.

3. Packet routing method with memory information

To realize the routing method with the memory information, we defined a state of the node described as follows;

$$y_{ij}(t+1) = \xi_{ij}(t+1) + \zeta_{ij}(t+1), \tag{1}$$

where

$$\xi_{ij}(t+1) = \beta \left(\frac{d_{ij} + d_{jg(p_i(t))}}{\sum_{k=1}^{N_i}(d_{ik} + d_{kg(p_i(t))})} \right), \tag{2}$$

and,

$$\begin{aligned} \zeta_{ij}(t+1) &= \alpha \sum_{\gamma=0}^{t} k_r^{\gamma} x_{ij}(t-\gamma) \\ &= \alpha x_{ij}(t) + k_r \zeta_{ij}(t-1). \end{aligned} \tag{3}$$

In Eq.(2), β is a controlling parameter, N_i is the number of the adjacent nodes of the ith node, $p_i(t)$ is a packet transmitted from the ith node at the tth time, $g(p_i(t))$ is the destination of $p_i(t)$, d_{ij} is the static distance between the ith node and the jth adjacent node and $d_{jg(p_i(t))}$ is the shortest distance between the jth adjacent node and $g(p_i(t))$. In Eq.(3), α is a scaling parameter of the memory information, k_r is a decay parameter, and $x_{ij}(t)$ is the transmission history of the jth adjacent node at the tth time, i.e.,

$$x_{ij}(t) = \begin{cases} 1 & (\min(y_{ij}(t+1)), \\ 0 & \text{(otherwise)}. \end{cases} \tag{4}$$

If $y_{ij}(t+1)$ of the jth adjacent node takes the smallest value among all the N_i adjacent nodes, a packet at the ith node is transmitted to the jth adjacent node. Then, the transmission history of the jth adjacent node, $x_{ij}(t)$, is updated according to Eq.(4).

4. Performance Evaluation of the Chaotic Routing Method

To evaluate the performance of the routing method with the memory information, we compared it with two kinds of conventional routing methods. The first one is the shortest path approach which is commonly employed by communication networks. The second one is a gain routing method. The gain routing method uses the distance information and the waiting time at adjacent nodes which is defined as follows;

$$\xi'_{ij}(t+1) = \beta \left\{ H \left(\frac{d_{ij} + d_{jg(p_i(t))}}{\sum_{k=1}^{N_i}(d_{ik} + d_{kg(p_i(t))})} \right) + (1-H) \left(\frac{q_j(t)}{\sum_{k=1}^{N_i} q_k(t)} \right) \right\}, \tag{5}$$

with $q_j(t)$ being the number of accumulating packets of the jth adjacent node at the tth time. The other parameters in Eq.(5) are the same ones defined in Eq.(2). We note that in equation (5), the first term expresses the distance from the ith node to the destination of the packet through the jth adjacent node and the second term expresses the number of packets that are being accumulated at the jth adjacent node. H in Eq.(2) decides the priority between the first term and the second term. If Eq.(5) of the jth adjacent node takes the smallest value among all the N_i adjacent nodes, i.e., the jth adjacent node is the closest to the destination of the packet and has the smallest number of accumulated packets in its buffer, a packet at the ith node is transmitted to the jth adjacent node.

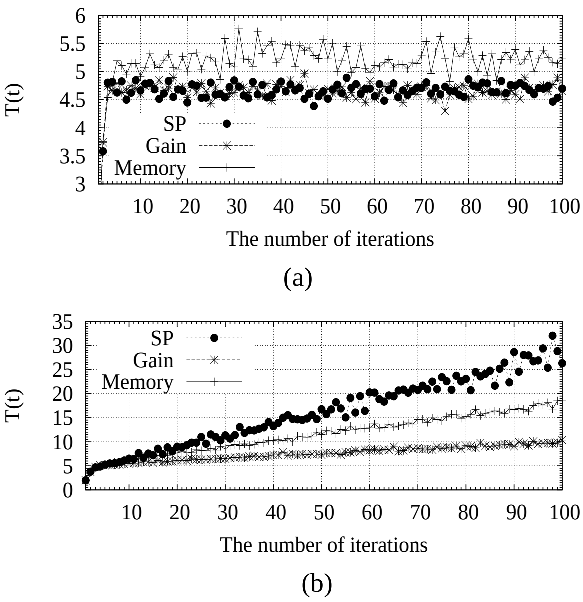
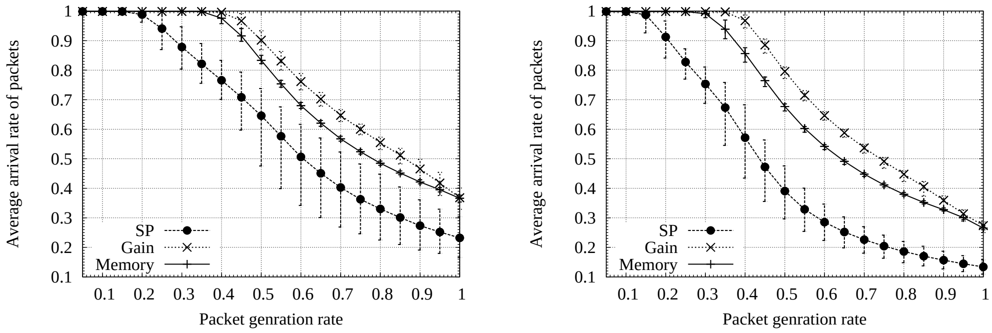


Figure 1: Relationship between the number of iterations and an average arrival time of the arriving packets at each iteration ($T(t)$) for (a) $\rho = 0.1$ and (a) $\rho = 0.4$.

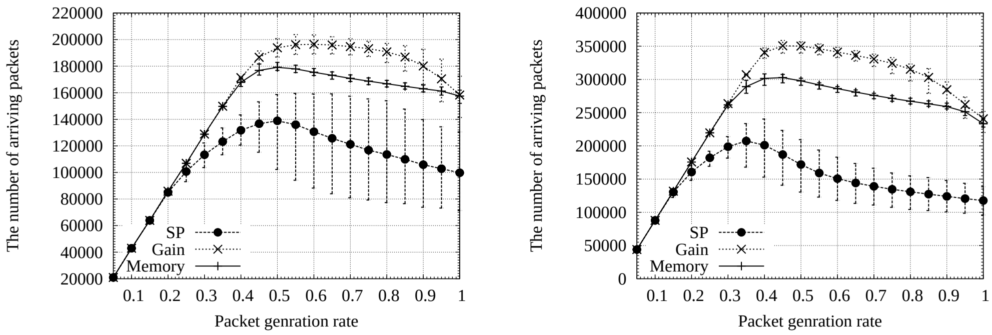
Numerical simulations are conducted as follows. An optimal adjacent node is selected using Eqs.(1) –(4), and the packets are simultaneously transmitted to their destinations at every node. We set the parameters in Eqs.(2)–(4) as follows: $\beta = 4.0$, $\alpha = 0.1$ and $k_r = 0.9$. We repeat the node selection and the packet transmission, I, for $I = 1,000$. We conducted 30 simulations to average the results. Because it has already reported that the packet-based computer networks have the scale-free property, we used the scale-free networks as the structure of the computer networks.

To evaluate the performance of the routing methods, we use the packet generating rate, ρ $(0 \leq \rho \leq 1)$, an average arrival time of the arriving packets at each iteration $T(t)$, and the total number of the arriving packets, N_a. Based on the packet generating rate, D packets are generated at each iteration. The number of generated packets at each iteration using the packet generating rate, ρ, is defined as follows;



(a) (b)

Figure 2: Relationship between the number of generated packets (D) and an average arrival rate of the packets (A) for (a) the number of nodes $N = 50$ and (b) $N = 100$.



(a) (b)

Figure 3: Relationship between the number of generated packets (D) and the total number of the arriving packets (N_a) for (a) the number of nodes $N = 50$ and (b) $N = 100$.

$$D = \rho \sum_{i=1}^{N} C_i, \tag{6}$$

with C_i being the processing capability and ρ is a controling parameter. In addition, an average arrival rate of the packets, A, is defined as follows;

$$A = \frac{1}{N_g} \sum_{t=1}^{T} N_a(t), \tag{7}$$

with N_g being the total number of the generated packets and $N_a(t)$ being the number of the arriving packets at the tth iteration.

First, we evaluate the average arrival time of the arriving packets at each iteration, $T(t)$ by the shortest path approach (SP), the gain routing method (Gain), and the memory routing method (Memory) for the scale-free networks. Figure 1 shows the average arrival time of the arriving packets at each iteration ($T(t)$). In Fig.1, although the average arrival time by the shortest path approach, the gain routing method and the memory routing method show similar performance (Fig.1(a)), the average arrival time by the shortest path approach increases if the packet generating rate ρ increases (Fig.1(b)). In addition, the gain routing method shows the shortest arrival time of the arriving packets among all the routing methods. The reason why the average arrival time by the gain routing method becomes shorter is that the gain routing method uses the waiting time information at the adjacent nodes.

Figure 2 shows the average arrival rate of the packets by the shortest path approach (SP), the gain routing method (Gain) and the memory routing method (Memory) for the scale-free networks. In Fig. 2, the gain routing method (Gain) and the memory routing method (Memory) keep higher average arrival rates of the packets (A) if the packets generation rate (ρ) increases as compared to the shortest path approach (SP).

Figure 3 shows the total number of the arriving the packets by the shortest path approach (SP), the gain routing method (Gain) and the memory routing method (Memory) for the scale-free networks. In Fig. 3, the gain routing method (Gain) and the memory routing method (Memory) transmit more packets to the destinations as compared to the shortest path approach (SP).

Clearly, as the congestion of the packets is alleviated in the case of the gain routing method and the memory routing method, the packets can be transmitted to the destinations using various routes even if the flowing packets become large in the scale-free networks. Further, the memory routing method uses the distance information and the memory information for routing the packets. Those information are possessed by each node, namely, the adjacent information such as the waiting time at the adjacent nodes is not used in the memory routing method. If the routing method uses the adjacent information, each node needs to communicate with the adjacent nodes to exchange the information, and the flowing packets increases by these exchanging. On the other hand, the memory routing method effectively selects the paths for routing the packets by the memory information without exchanging of the information between the nodes.

5. Conclusions

In this paper, we study the routing method with memory information which works to select the paths for the packets by eliminating the traffic congestion. The obtained results indicate that the memory routing method shows similar performance as compared to the routing method which uses the distance information and the waiting time information for routing the packets. The advantage of the memory routing method is that the memory routing method does not use the adjacent information such as the waiting time at adjacent nodes for routing of the packets. Thus, the memory routing method has much possibility to apply into the real communication networks because the exchanging of the information between nodes is not necessary in the memory routing method.

In our future work, the use of memory information may be combined with consideration of the use of cellular automata for congestion elimination. In addition, an order parameter may be used to indicate the phase transition point between free state and congested state for the network.

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