2016 International Symposium on Nonlinear Theory and Its Applications,
NOLTA2016, Yugawara, Japan, November 27th-30th, 2016

A Study of a probabilistic routing method based on packet transmission capacity

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Abstract—Recently, the data packet flow increases on the Internet because of wide spread of mobile devices or high-speed wireless communications. The data packets are often lost or delayed if the communication networks are congested. The shortest path protocol that is commonly used in the real-world system is not effective for routing the packets because the one transmits data packets using only the distance information of the communication networks. Therefore, the packet congestion easily occurs at the hub nodes. Thus, an efficient routing method which effectively controls the data flow in the communication network is desired to remove the packet congestion. From this view point, a probabilistic routing method for the communication networks has been proposed. In this method, each node decides the transmitting nodes using probabilistic way based on the number of holding packets and degree of the adjacent nodes. However, this method doesn't consider the transmission capacity. Thus, the packets are transmitted to the nodes that store large amount of packets exceeding the transmission capacity. The packets are then accumulated at these nodes, and this causes the congestion on the network. From this view point, we proposed another probabilistic packet routing method using the number of holding packets at adjacent nodes and transmission capacity in this study. From the results of numerical experiments, the proposed method effectively avoids the congestion of packet in comparison to the conventional shortest path routing and the conventional probabilistic routing method.

1. Introduction

Recently, the data packet flow increases on the Internet because of wide spread of mobile devices or high-speed wireless communications. The data packets are often delayed because of the congestion in the communication networks. As the solution for tackling these problems, using access restriction is implemented. However, it doesn't consider the users satisfaction.

It has been already reported that the communication networks have scale-free property[1, 2]. Then, the shortest path protocol[3] that is commonly used in the real-world system is not effective for routing the packets because the one transmits data packets using only the distance information of the communication networks. As a result, the packet congestion easily occurs at the hub nodes. Thus, an efficient routing method which effectively controls the data packets flow in the communication networks is desired to remove the packet congestion[4, 5]. From this view point, a probabilistic routing method for the communication networks has been proposed[6]. In this method, transmitting node of a packet is determined using the number of holding packets and degree at adjacent nodes. Although this routing method can alleviate the packet congestion, we confirmed that the packets are still trapped at the nodes. The reason why the packets are trapped at some nodes is that the transmission capacity is evaluated used for routing packets by the probabilistic method. From this view point, we proposed a new probabilistic packet routing method using the number of holding packets and transmission capacity at adjacent nodes. From the results of numerical experiments, the proposed method effectively avoids the congestion of packet in comparison to the conventional routing methods.

2. Network model

In this study, we use a simple undirected graph composed by nodes and links as a communication network model. We also employ the scale-free networks[7] as a topology of communication network. The scale-free network is generated by the following steps. First, a complete graph in which every node has degree of K is generated. Then, a node which has degree of k is added to an existing network. Each branch of newly added node is connected to the nodes using preferential selection probability $\Pi(k_i) = k_i / \sum_{j=1}^{\acute{N}} k_j$, where k_i is the degree of the ith node, $\acute{N}$ is the number of nodes in the existing network. Node attachment is repeated until a terminating condition, $N = \acute{N}$, is satisfied.

Figure 1 shows an example of scale-free networks by $N = 100$ and $K = 3$. In Fig. 1, the nodes which have large circle stand for the hub nodes. Figure 2 shows the degree distribution of scale-free networks. In Fig. 2, although a few nodes have the large degree, most of the nodes have low degree.

In this study, each node has a buffer to store the packets and the packets are transmitted to the adjacent nodes using First-In First-Out rule. Moreover, a single iteration is defined as determinations of the transmitting nodes at the nodes and transmissions of packets. The ith node transmits

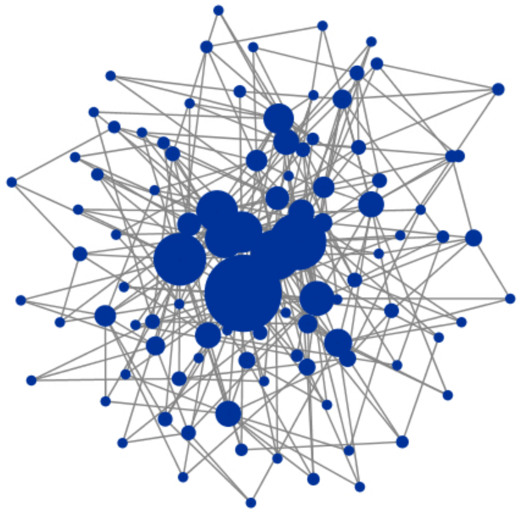


Figure 1: An example of scale-free network (N = 100).

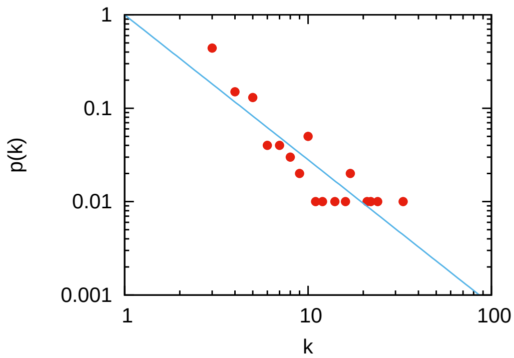


Figure 2: Degree distribution of scale-free networks.

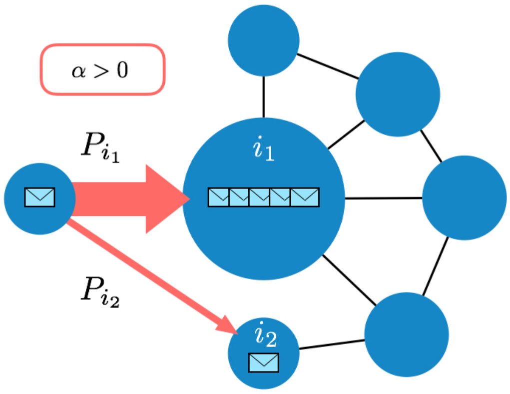
C_i packets to its adjacent nodes during the single iteration. The transmission capacity C_i of the ith node is defined as $C_i = 1 + k_i$. In each iteration, R packets are generated in the network with randomly selected sources and destinations. Once a packet arrives at its destination, it will be removed from the network.

3. A probabilistic routing method using degree and holding packet information

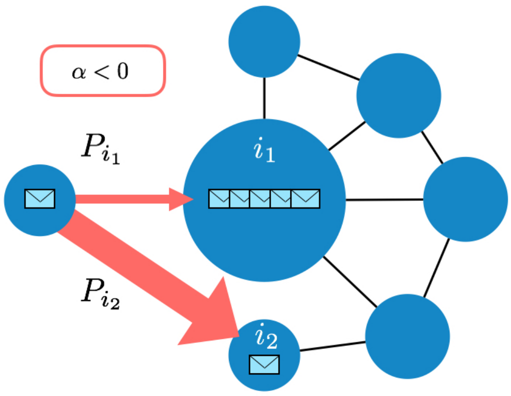
A conventional probabilistic routing method[6] uses the degree information and the number of holding packets at adjacent nodes to transmit the packets to their destinations. The conventional method determines a transmitting node using the following probability:

$$P_i(t) = \frac{k_i(n_i(t) + 1)^{\alpha}}{\sum_j k_j(n_j(t) + 1)^{\alpha}}. \quad (1)$$

In Eq. (1), $P_i(t)$ is a probability that the ith node is selected as the transmitting node at the tth iteration. k_i is the degree of the ith node, $n_i(t)$ is the number of holding packets in the ith node at the tth iteration, α is a controlling parameter. If a destination of a packets is found among adjacent nodes, the packet is transmitted to the destination without using Eq. (1). By using Eq. (1), although a packet is easily transmitted to the hub nodes if α takes large value, the packets are hardly transmitted to the hub nodes if α takes negative value.



(a) a positive α case



(b) a negative α case

Figure 3: Conventional probabilistic routing method[6]

Figure. 3 shows schematic diagrams for each parameter. In Fig 3, the transmission probability of the i_1th node and i_2th node are denoted by P_{i_1} and P_{i_2}. The transmission probability then changes by the value of α in Eq. (1). In Fig. 3(a), the transmitting probability to the i_1th node which has large degree and the large number of holding packets increases if α is positive. On the other hand, if α is negative, the transmitting probability to the i_2th node increases. In this study, packet congestion rates for various α cases are used to evaluate the performance of conventional probabilistic routing method. The packet congestion rate is defined as follows:

$$\eta = \frac{1}{R\Delta t} \frac{\sum_{t=1}^{T-\Delta t} \Delta Np}{(T - \Delta t)}. \quad (2)$$

In Eq. (2), R is the number of packets generated at each iteration. ΔNp is define by $\Delta Np = N(t + \Delta t) - N(t)$ where $< \cdots >$ indicating an average over the time windows of width Δt, and $N(t)$ is the number of packets in the network at the tth iteration. The packet congestion rate $(0 \le \eta \le 1)$ indicates that the network is congested as η approaches 1. In the numerical simulations, we set the number of nodes $N = 100$ and the number of degree $K = 3$. In addition, we repeated the packet transmission for 1000 iterations. Then, we conducted the numerical experiments for 10 times and the averaged the results.

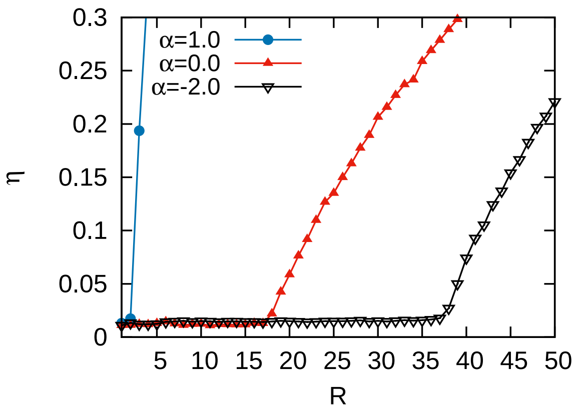


Figure 4: Relationship between the number of generating packets at each iteration, R, and the congestion rate for various α cases.

Figure 4 shows the packet congestion rate for various α cases. From Fig. 4, the packet congestion rate rapidly increases when R is larger than 1 if α is set to -1. The congestion rate rapidly increases when R is larger than 17 if α is set to 0 and 37 if α is set to -2. In addition, we can see the phase transition point[8] between a free flow state and a congested state at $R = 37$ if α is set to -2. The congestion rate by $\alpha = -2$ is lower than that by $\alpha = 1$. Because most of the packets are transmitted to the destinations through the hub nodes in case by $\alpha = 1$, the packet congestion easily occurs at the hub nodes and the congestion spreads to the other nodes. If we set α to -2, the packets are transmitted to the destinations using the paths that don't go through the hub nodes. Therefore, the transmitting paths of packets are widely distributed throughout the networks and the packet congestion hardly occurs in the communication networks.

Figure. 5 shows the average number of packets at each node for the conventional probabilistic routing method. In Fig. 5, the numbers of packets of nodes with high degree are larger than their transmission capacities. The congestion is then accumulated at these nodes because these nodes cannot transmit the packets over their transmission capacities. This problem seems to lie in the fact that the transmission capacity of the adjacent node is not considered to route the packet. We then propose a new probabilistic packet

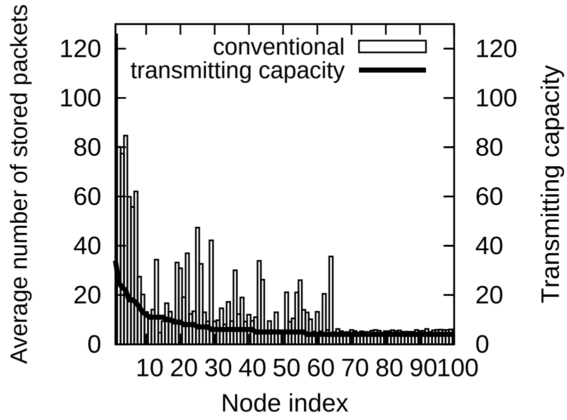


Figure 5: Relationship between the node index and the average number of packets at each node for $R = 40$ and $\alpha = -2.0$ case. The node index is sorted in descending order of degrees of the nodes.

routing method that incorporates transmission capacity and the number of holding packets at the nodes.

4. A probabilistic routing method using transmission capacity and the number of holding packets

In the previous section, we clarify that the congestion spreads to whole network because the transmission capacity is ignored to route the packets. We then propose a new probabilistic routing method. In our proposed method, each node determines the transmitting node for routing the packets using the following probability:

$$P_i(t) = \frac{(\frac{n_i(t)+1}{C_i})^{\gamma}}{\sum_j (\frac{n_j(t)+1}{C_j})^{\gamma}}. \quad (3)$$

In Eq. (3), $P_i(t)$ is the probability that the ith node is selected as the transmitting node at the tth time, C_i is the transmission capacity of the ith node, $n_i(t)$ is the number of holding packets in the ith node at the tth time, γ is a controlling parameter. In the same may as the conventional probabilistic routing method, if the node founds the destination of a packet among the adjacent nodes, the packet is delivered to its destination without using Eq. (3). By using Eq. (3), the packets are easily transmitted to the nodes which have the packets less than their transmission capacities if γ takes negative value. We compared the congestion rate by the conventional probabilistic method[6] with that by proposed method. Same experimental conditions used in the previous section are applied to these numerical simulations. The parameters in Eq. (1) and Eq. (3) are set as follows: $\alpha = -2.0$ and $\gamma = -10.0$.

Figure 6 shows the congestion rate for each method. In Fig. 6, the congestion rate by the conventional probabilis-

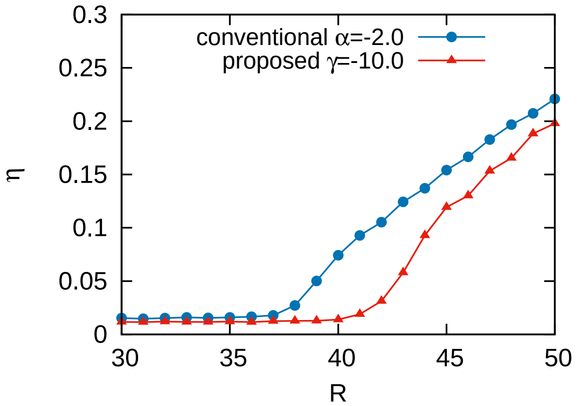


Figure 6: Relationship between the number of generating packets at each iteration, R, and the congestion rate by the conventional probabilistic routing method ($\alpha = -2.0$) and the proposed probabilistic routing method ($\gamma = -10.0$).

tic routing method rapidly increases if R is larger than 37. In addition, the congestion rate by our proposed method rapidly increases if R is larger than 41. From these results, the proposed method effectively avoids the packet congestion.

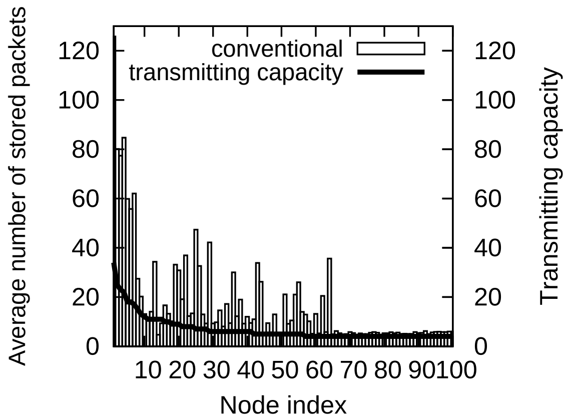
Figure 7 shows the average number of holding packets at each node by the conventional method and proposed method. In Fig. 7(a), although the number of holding packets of the nodes with high degree by the conventional method is larger than their transmission capacities, the nodes by the proposed method keeps lower holding packets than their transmitting capacities. From these results, we confirmed that our proposed method avoids the congestion of packets by using the transmitting capacity effectively.

5. Conclusion

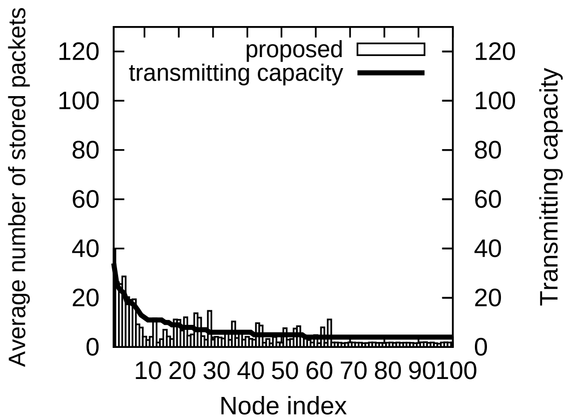
In this study, we proposed a probabilistic routing method which incorporates not only the number of holding packets but also transmitting capacity for routing the packets. First, we confirmed that the conventional routing method cannot remove the packets at the hub nodes because the conventional method doesn't consider the transmission capacities. From this viewpoint, we proposed the probabilistic routing method using transmission capacity and the number of holding packets. From the results of numerical experiments, the proposed method avoided the congestion of packets by using the transmitting capacity effectively.

In future works, we apply our proposed method to various topologies of realistic communication networks.

The research of T.K. was partially supported by a Grant-in-Aid for Young Scientists (B) from JSPS (No.16K21327).



(a) Conventional method



(b) Proposed method

Figure 7: Relationship between the node index and the average number of packets at each node for $R = 40$ to Fig. 7(a) $\alpha = -2.0$ and Fig. 7(a) cases. The node index is sorted in descending order of degrees of the nodes.

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