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A Construction method for disjoint paths with transmission reliability on communication networks

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Abstract—The transmission networks such as mobile communication networks continues to expand because of the huge growth of users. Even if the networks increase, the Quality of Service should be maintained. To overcome this problem, finding the working paths and the efficient alternative paths are used to guarantee transmissions on the communication networks. A conventional technique constructs both a working path and an alternative path for transmission, however, the information of the other paths are ignored. In this study, we propose a construction method for the working paths and its alternative paths using the information from the other paths, achieving our proposed method removes the packet congestion in comparison to the conventional techniques.

1. Introduction

Recently, the QoS guarantee degrades because of link (or server) failures in the network by the expansion of the transmission network. If the transmission between users is not established suitably, these users frustrate because of the failure of access. An important key to overcome this problem is reliability of the communication network. The reliability of the communication network represents a probability of being able to establish communication path on the communication network even if failures in the network have occurred. To tackle this problem, two types of transmission paths are prepared before transmission of a packet. One is a working path used for common transmission and another is an alternative path used if the working path fails. The alternative path is constructed using the node set without used by its working path. In general, two paths are denoted as "disjoint paths." If we find the working path and the alternative path whose reliability are high, the QoS in the communication networks increases. To construct these efficient paths, the working path and the alternative path should be disjointed; the node and link set used by the working paths and those by alternative paths are independent. Finding the best combination of disjoint paths is the non-linear optimization problem. Further, because the communication networks have the scale-free property [2] , the node distribution by constructing the disjoint paths is biased. Figure 1 shows how many times each node is used for the disjoint paths. In these simulations, we set the number of nodes of network to 100, and cost of each link to 1. In Fig. 1, many paths go through the nodes whose degree are larger than the others. The congestion of packets occurs on these nodes. The QoS is then degraded by the congestion on the communication network. Therefore, finding the effective disjoint paths is important not only to enhance the reliability of packet transmission but also to avoid the congestion in the network.

In this study, we propose a new method for finding the effective disjoint paths using availability of nodes in the networks. To evaluate the effectiveness of our the proposed method, we use the probability graph whose links fail or broken with a probability. Results of simulations indicate that our proposed method constructs better disjoint paths, achieving the congestion is well removed.

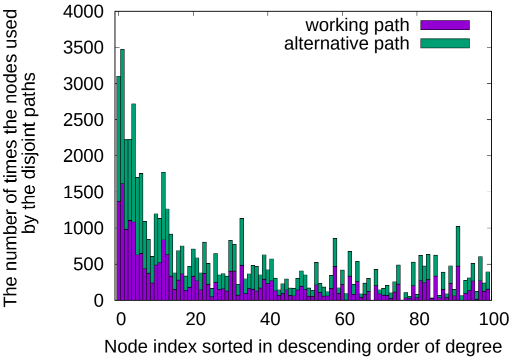

Figure 1: Node distribution of the disjoint paths by the conventional method for the scale-free networks.

2. Problem formulation

We use an undirected network $G = (V, L)$, where $V = \{v_1, v_2, v_3, ..., v_N\}$ is a set of nodes and L is a set of links as a network model. Each link $(i, j) \in L$ has a failure probability

λ. A cost of each link, c_{ij}, is then defined follows:

$$c_{ij} = \begin{cases} \lambda & \text{if } (i,j) \in L, \\ \infty & \text{otherwise.} \end{cases} \quad (1)$$

A path from node s to node t in the network is described by $p_{st} = \{s, (s,i), i, ..., j, (j,t), t\}$. A cost of a path $p_{st} = \{s, (s,i), i, ..., j, (j,t), t\}$ is then defined as follows:

$$C(p) = \sum_{\substack{i \in p \\ i \neq s \neq t}} \frac{b_i}{N(N-1)} + \sum_{(i,j) \in p} \frac{c_{ij}}{c_{total}}, \quad (2)$$

where b_i is the number of times the ith node is used for the working paths, c_{total} is the total costs in the network. A transmission reliability of a path is then defined as follows:

$$Tr(p_{st}) = e^{-C(p_{st})}. \quad (3)$$

The most reliable pair of disjoint paths from s to t is given by,

$$\max Tr(p^w_{st} \cup p^a_{st}) = Tr(p^w_{st}) + (1 - Tr(p^w_{st}))Tr(p^a_{st}), \quad (4)$$

where p^w_{st} is a working path from s to t, p^a_{st} is an alternative path from s to t. The objective function for finding the effective disjoint paths is then defined as follows:

$$\max \mathrm{Tr}(G) = \sum_{\substack{\forall i,j \in V \\ i \neq j}} \max \mathrm{Tr}(p^w_{ij} \cup p^a_{ij}), \quad (5)$$

where G is an undirected network.

3. Path searching algorithm

Although the conventional method for the disjoint paths [1] uses predefined link costs for constructing the working and alternative paths, we employ the optimum path strategy [4] which considers the node betweenness centrality to assign the weight of the link. By using the optimum path strategy [4], we expect that the biased node distribution for making the paths is equalized and the congestion of networks is alleviated. An algorithm of our proposed method in this study is described as follows:

-step 1 Searching the shortest paths between all of the nodes.

$$p^w \leftarrow \text{Shortest path Search}(V, L, W(t)),$$

where V is the set of nodes, L is the set of links, $W(t)$ is the set of weight of link at the tth time. Here, $w_{ij}(t)$ is the weight of the links between the ith node and the jth node at the tth time. We set $w_{ij}(0)$ to c_{ij} in Eq. (1).

-step 2 Adding the weight to the link.

To avoid the nodes used by the working paths for constructing alternative paths, we add an weight to links to which the node whose betweenness centrality is the highest among the whole working paths is connected. The adding weight of link is defined as follows:

$$w_{ij}(t+1) = \beta w_{ij}(t),$$

where β is a controlling parameter of adding link cost. In this study, we set β to 2.

-step 3 Searching the alternative paths by using the weight $W(t+1)$.

$$p^a \leftarrow \text{Shortest Path Search}(V, L, W(t+1)),$$

-step 4 Calculating the transmission reliability.

The transmission reliability of the network is calculated using the Eqs. (2) – (5).

We repeated from the step 1 to the step 4 until a terminating condition is satisfied. In this study, we repeated these steps 50 times.

4. Simulation

To investigate the reliability of our proposed method, we use a probabilistic graph in these simulations. In the probabilistic graph, each link have failure probability. In these simulations, the following conditions are assigned to the networks.

- A state of link is either normal or failed.
- Each link has an independent probability for link failure.
- States of all links are determined using the link failure probabilities at each iteration.
- States of failure links are repaired after a certain period of time.

In these simulations, we evaluated the congestion rate [5] for the conventional method [1] and the proposed method. To do this, we generated the packets on the networks. We then changed the states of links using the probabilistic graphs and evaluated the congestion rate. We use two types of network. The first is the scale-free network [2] (Fig. 2) and another is the random network [3] (Fig. 3). The number of nodes in the network, N, is set to 100. In these simulations, each node has a buffer to store the packets. The packets in the buffer is transmitted to the adjacent nodes using First-In First-Out(FIFO) principle. In addition, each node transmits a packet to its adjacent node at each iteration. A single iteration is defined by the transmission of the packets to the nodes. We generate R packets in the network at each iteration. The source node and the terminal node of each packet are randomly determined. A packet is

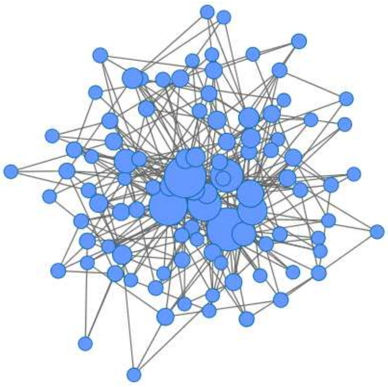

Figure 2: The scale-free network

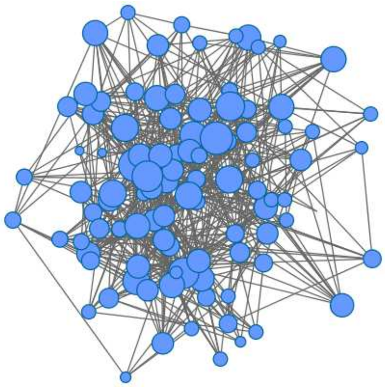

Figure 3: The random network

removed if the node to which the packet has been transmitted has no empty in its buffer. In addition, a packet is also removed if the packet goes through the failure link. Further, if a packet arrives at its terminal node, the packet is removed. A packet is first transmitted to its terminal node using the working path. If the packet is removed from the network, the packet is again transmitted to its terminal node using the alternative path. In this study, the failure probability of each link is set to 1% and a link is recovered after five iterations. The buffer size of the node is set to 300. We set the number of iterations T to $1,000$. Next, the network congestion rate, $0 \leq \eta \leq 1$, is defined as follows:

$$\eta = \frac{\sum_{i=1}^{T}(n(t) - n(t-1))}{RT}, \quad (6)$$

where $n(t)$ is the number of packets in the network at the t th time. If η is small, the network is free flow, otherwise, the network is congested. The retransmission rate, $0 \leq \delta \leq 1$, is defined as follows:

$$\delta = \frac{x}{U}, \quad (7)$$

where x is the number of retransmissions, U is the number of transmissions. If δ is small, the packet transmissions are successfully conducted, otherwise, the transmissions are frequently interrupted by buffer constraint or link failure. Figure 4 shows the number of times the nodes are used by the disjoint paths by our proposed method. In Fig 4, the nodes with large degree show less employed rate than the ones by the conventional method (Fig. 1) to construct the disjoint paths. The congestion rates and the retransmission rates for the scale-free networks by our proposed method and the conventional method are shown in Figs. 5 and 6. In Figs.5 and 6, the proposed method shows lower congestion rate than the conventional method if the number of generating packets at each node is between 5 and 25. The congestion rate and the retransmission rate for the random network by both methods are shown in Figs. 7 and 8. In Figs. 7 and 8, the proposed method shows lower congestion rate than the conventional method if the number of generating packets at each node is between 5 and 25. From these results, our proposed method shows better congestion rate for the scale-free network than those by the random network. This is because the hub nodes in the scale-free networks are avoided for constructing disjoint paths.

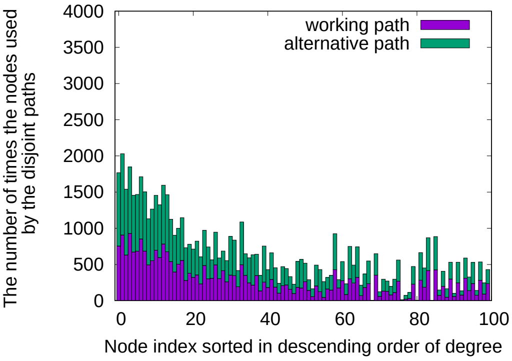

Figure 4: Node distribution of disjoint paths by the proposed method for the scale-free networks.

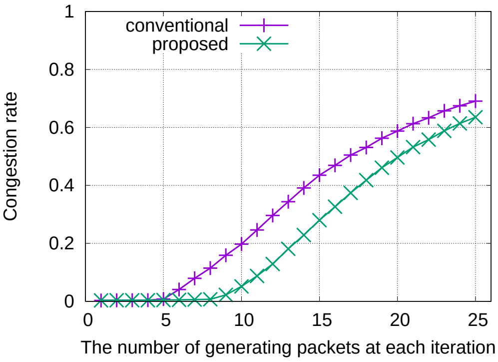

Figure 5: Congestion rate for the scale-free network

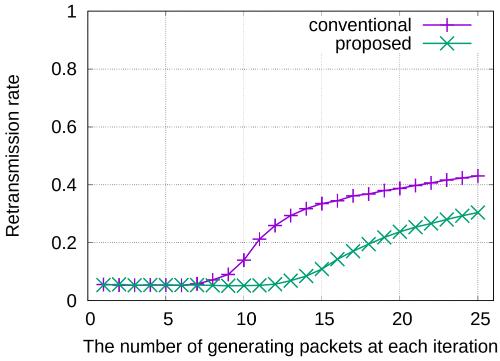

Figure 6: Retransmission rate for the scale-free network

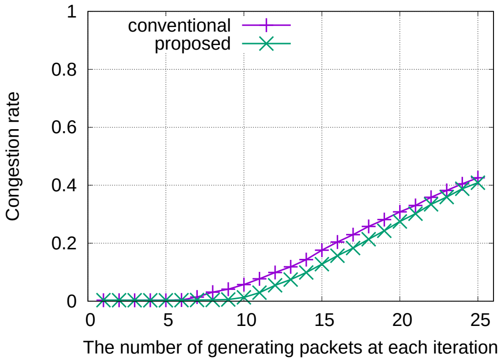

Figure 7: Congestion rate for the random network

5. Conclusions

In this study, we proposed a new construction method for disjoint paths that effectively avoids the congestion at the hub nodes in the communication networks. We evaluated our proposed method by the congestion rate and the retransmission rate. From the results of numerical simulations, our proposed method shows lower congestion rate and retransmission rate than the conventional method. In future works, we evaluate our method by various realistic network conditions to investigate an applicable possibility of our method to the real world system.

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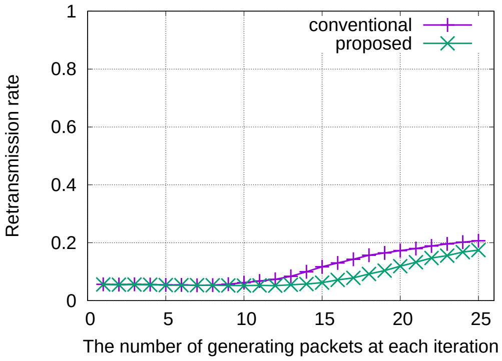

Figure 8: Retransmission rate for the random network

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