Abstract—In a high-speed backbone network, the failure of a network link may cause large data losses, so it is necessary to reserve spare network resources for faster recovery. The conventional protection methods to reserve backup routes do not consider the failure probability of each network link, so the same amount of network resources for the backup route are needed regardless of the failure probability of network links. This leads to a decrease in the number of connections that can be accepted into the network. This paper proposes a routing and capacity allocation method that guarantees the expected value of allocated capacity. We formulate a mixed integer liner programming model for the proposed method. We conduct simulations to study the advantage of the expected capacity guaranteed routing over the conventional routing method in terms of bandwidth blocking probability. The results show that the proposed method reduces the bandwidth blocking probability to about 1/3 as compared to that of the conventional path protection method.

I. INTRODUCTION

In recent years, due to rapid popularization of the Internet and increased number of connected devices, a high speed transfer capability is required for the backbone network. However, a lot of data is lost even when a failure occurs in one network link and it may have a huge influence on various services. In order to prevent such a situation, one of the methods widely used for recovering from link failures is a path protection method which prepare a backup path for each path before configuring the network [1].

The prediction methods of network failure based on data mining are being studied [2], [3]. However, the conventional routing methods do not consider failure probability and backup paths are prepared for all paths uniformly. For this reason, there is a problem that the same link capacity is reserved for backup no matter whether the possibility of failure of the links is high or not. It is considered that network resources can be efficiently used by changing the amount of securing the backup path as necessary based on the link failure probability.

This paper proposes a routing and capacity allocation method that guarantees the expected value of allocated capacity. We formulate a Mixed Integer Liner Programming (MILP) model for the proposed method and conduct simulations to study the advantage of the method over the conventional routing method. The results show that the proposed method reduces the bandwidth blocking probability compared to that of the conventional path protection method.

II. EXPECTED CAPACITY GUARANTEED ROUTING

The conventional protection method did not care the failure probability of links and a backup path of a certain capacity was prepared for a primary path regardless of reliability of paths. We propose the expected capacity guaranteed routing method which calculates the expected value of available capacity on the allocated route based on the failure probability of each link and selects a route that achieves a certain expected value or more. This method increases the number of connections that can be accommodated in the network compared to the protection method because the appropriate network resources are used for the backup route according to the failure probability of the links.

The failure probability of system, λ is defined as the probability per unit time that system experiences a failure. The reliability of system, \( R(t) \) is defined as the probability that the component or system experiences no failure during the time interval 0 to t. There is a relationship such as \( R(t) = e^{-\lambda t} \) between failure probability and reliability. The expected value of capacity is calculated as the product of the allocated capacity of the route and the reliability of the route, which is the product of the reliability of the links in the route.

We assume a connection request is represented by \( r = \langle s, d, B_{req}, Q, t \rangle \), where s and d are the source and destination nodes, \( B_{req} \) is the capacity requirement, \( Q(0 \leq Q \leq 1) \) is the expected capacity quality that shows the ratio of the expected capacity to the required capacity, and t is the connection holding time.

When \( r = \langle s, d, B_{req}, Q, t \rangle \) is given, the expected capacity guaranteed routing selects K paths between s and d, respectively, total reserved capacity on the K paths is at least \( B_{req} \), and total expected capacity on the K paths is at least \( QB_{req} \). To increase the number of connections that can be accommodated in the network, this method selects the route with the lowest cost, which is defined as the product of the link distance and the traffic capacity flowing on the link.

We develop the MILP model for expected capacity guaranteed routing as follows.
Objective:
\[
\text{minimize } \sum_{k \in K} \sum_{(i,j) \in E} y_{ij}^k \cdot d_{ij}
\]

Constraints:
\[
\sum_{j: (i,j) \in E} x_{ij}^k - \sum_{j: (j,i) \in E} x_{ji}^k = \begin{cases} 
1, \forall k \in K, i = p \\
0, \forall k \in K, i \neq p \end{cases}, \forall (i,j) \in E \\
0 \leq \sum_{k \in K} y_{ij}^k \leq \min(B_{req}, c_{ij}), \forall (i,j) \in E \\
\sum_{k \in K} b_k \geq B_{req} \\
\sum_{k \in K} b_k \sum_{(i,j) \in E} (1 - e^{-\lambda_{ij} t}) \cdot y_{ij}^k \geq QB_{req} \\
x_{ij}^k = \{0, 1\}, \forall k \in K, (i,j) \in E. \\
y_{ij}^k \geq b_k + U(x_{ij}^k - 1), \forall k \in K, (i,j) \in E \\
y_{ij}^k \leq U x_{ij}^k, \forall k \in K, (i,j) \in E \\
y_{ij}^k \geq 0, \forall k \in K, (i,j) \in E
\]

E, V, and K are a set of links, nodes, and path number k. \((i,j)\) is a link between node \(i\) and \(j\), \(d_{ij}\), \(\lambda_{ij}\), and \(c_{ij}\) mean the length, the failure rate and the link capacity of \((i,j)\), respectively. \(p\) and \(q\) show the source node and the destination node. \(U\) is a large number such that \(U = \max_{(i,j) \in E} c_{ij}\). \(x_{ij}^k\) is a boolean variable that equals 1 if the \(k\)th path uses \((i,j)\) and 0 otherwise. \(b_k\) is traffic capacity that can flow through \(k\)th path. \(y_{ij}^k\) is a variable to linearize the constraints and coincident with \(x_{ij}^k \cdot b_k\) in the optimal solution. We also use Bernoulli’s inequality for an approximate calculation of route reliability.

III. SIMULATION AND DISCUSSION

We use the topology with 5 nodes and 8 links as shown in Fig. 1. The number in each node shows the node number and the number beside each link shows the length of the link.

The arrival of connections follows a Poisson distribution and the demand holding time is geometrically distributed with a mean of 4 seconds. We conduct simulations for different number of demands. In each simulation, 10,000 demands are generated randomly and each demand has random source and destination nodes. The requested capacity \(B_{req}\) is randomly chosen from \{1, 4, 8, 16\} and the expected capacity quality \(Q\) is 1. The maximum number of routes \(|K|\) is 3. The link capacity is set to 100 and the failure probability of each link is chosen from \{0.01, 0.03, 0.05\}. The recovery time of links is geometrically distributed with mean 5 seconds and after recovery, the failure probability is re-chosen. In this simulation, We capacity \(B_{req}\) and the other is the backup path with capacity \(QB_{req}\) as the conventional method with using backup path.

Fig. 2 shows the BBP performance of each routing method at different number of the arrival connections. In all cases, the BBP of the link disjoint two-path routing is the highest. When the number of connection occurrences per second is 10 or more, the BBP of the link disjoint two-path routing is about 3 to 5 times higher than that of the expected capacity guaranteed routing. It can be said that the expected capacity guaranteed routing accepts more connections than the link disjoint two-path routing under the high load condition and the proposed method improves the utilization efficiency of the network from the conventional method while considering fault tolerance.

IV. CONCLUSION

The conventional path protection methods do not consider the failure probability of network links. This leads the excessive capacity allocation for high reliability links and the excessive allocation causes a reduction in the number of connections that can be accepted into the network. This paper proposed the expected capacity guaranteed routing method that guarantees the expected capacity value of the allocation exceeds the requested value. We developed the MILP model for the proposed method. Our simulation results showed that the proposed method reduces the BBP by 1/5–1/3 compared with conventional protection method.

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REFERENCES