Multi-Topology Traffic Engineering with Metrics not based on ECMP

Masashi Hashimoto and Taku Ishizaki

Abstract—**In this paper, we propose a method that uses more than one metric to realizes Multi-Topology based Traffic Engineering (TE). The characteristics of our proposal are that no metric is based on ECMP (Equal Cost Multi Paths) and only the shortest path is selected. This simplifies the transmission processing within a network. After decomposing each flow that realizes TE, we determine which metrics are to be used for each flow. We describe how to determine paths and cost sets, which are groups of link costs, and describe a simulation conducted. From the viewpoint of routing complexity, it is better to have a small number of cost sets. Simulation results show that the required number of cost sets is between 1/3 to 1/2 the number of nodes and is also lower than the number of the entire flows, which is of the order of 2n where n is the number of nodes.**

Index Terms—**Multi-Topology, traffic engineering, metric. OSPF, MT-OSPF, shortest path.**

I. Introduction

As rich content distribution such as large file transmission that requires bandwidth, distribution of stream broadcasting and IP phone is expanding, the Internet traffic has become more varied and the volume of traffic that flows into the core network keeps increasing. For this reason, TE (Traffic Engineering) technology is becoming ever more important. The technology that disperses traffic across a network can reduce the maximum utilization ratio of links within the network, in another words "the congestion ratio"[1].TE technology includes MPLS-TE [4], which uses the advanced route setting technology of MPLS [2,3] and OSPF-TE [5,6], which disperses traffic between ECMPs (Equal Multi-Paths) by using the inverse of the link bandwidth as a metric in OSPF (Open Shortest Path First).

As for MPLS-TE, traffic is transmitted over one or multiple LSP(s). The bandwidth and path that each LSP uses can be calculated by LP (Linear Programming) [1]. This calculation minimizes the congestion ratio. The calculation is carried out externally once the network topologies and traffic between each starting and ending nodes are given. In the case of full mesh traffic, if the number of nodes is N, there are N∗(N-1) traffic streams. This means that paths must be set for N^2 order LSPs or an even greater number if the traffic is split.

As for OSPF-TE, a link cost that is proportional to the inverse of the link capacity is defined for each link, and routing is carried out using metrics that identify the shortest paths, where the overall costs are determined by the minimum cost of each path. In this way, traffic can flow over a path with wider bandwidth, and the congestion ratio can be reduced. Even more, if there are multiple shortest paths (ECMP) that have the same costs, traffic is to be spread evenly across those paths. However, this method, which is different from that of MLPS-TE, does not calculate paths externally and does not set paths expressly. This means that the best path does not necessarily offer the best congestion ratio. However, it does the advantage of easier implementation due to the simplicity of the route setting algorithm; only the shortest path is used.

MPLS-TE is a strong TE method but it does require an advanced infrastructure. The number of paths that need to be set is of the order of N∗(N-1) for full mesh traffic. Also, the protocol overheads for route setting are necessary. That is why some studies determine link cost where the shortest path is be used for route setting and it becomes the path associated with TE [7,8]. As for studies on link cost determination, there are (1) a study on determining link cost in a heuristic way [7] and (2) a method with LP [8]. In (1), the cost that has the best TE effect is determined by finding the path that has best TE effect by repeatedly changing costs to identify the shortest path with high TE effect. In (2), link costs are determined by solving the dual problems of the LP problem of TE. However, in (1), the acquired value comes close to the best value determined with optimization by TE calculation (denoted by α_{TE}). but it is not a perfect fit. It is also considered that results depend on conditions. Some degradation in α_{TE} occurs. As for (2), costs that realize α_{TE} can be obtained by using the shortest path. However, if the costs are set as link costs, many shortest paths will appear (ECMP). This node response to ECMP is different from the response to the above mentioned ECMP in OSPF and is more complex. It needs to identify N^2 order traffic streams and output to the output port designated with each defined branching ratio. The branching ratio and the output port use values calculated by the LP Equation of TE. However, it is unrealistic to demand that all node devices be able to perform this complex function. Also, it loses the meaning of using metric based routing, which is supposed to be that the route determination algorithm is simple

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and easy to implement.

Therefore, in this our study, we considered a method that allows the congestion ratio to be set as α_{TE} as in (1) and a more practical way than (2) to ease implementation concerns. We propose the use of multiple metrics. As in MT-OSPF [9], different metric IDs are defined for the multiple link costs and sorted. We call a group of each link cost sorted with ID a "cost set." The shortest path is calculated for each cost set and each ID has different shortest path. Each traffic is transmitted over one or more flows. We attach an ID to each flow and carry out routing with the shortest path of metric that corresponds to the ID at each node device.

The characteristic of our proposed method is that ECMP does not exist in the shortest path of each cost set. So there is only one shortest path, which means that when a flow is transmitted at a node, there is no need to split the flow. Traffic must be diverted into one or multiple flows, and needs to receive an ID when entering into a network. This process is also required in conventional methods as well, for example, WRR (Weighted Round Robin) technology and expanding the TOS field [9]. Here, it is considered that the greater the number of required cost sets, or the required number of IDs, there are, the more complex the routing table becomes. That is why evaluations on how to acquire cost sets and the number of cost sets are important. While designing a network that uses multiple metrics has been formulated in the literature as an LP problem [10], methods of determining the metrics themselves have not been shown. In our study, starting with the metrics gained thorough solving the dual problems of the LP Equation of TE, we consider the acquisition of cost sets that do not use ECMP. Some previous studies have used the multi-topology approach to achieve the efficient use of network resources [11]. However, those studies differ from the method introduced in this paper, including the application domain, because they failed to consider the uneven wireless environment and did not control of metrics that use link-costs.

MRC (Multiple Routing Configurations) is a recent routing method that uses multi-topologies. In this method, a network is split into multiple configurations and the network part, through where traffic passes, is controlled by the metrics used for routing [12]. While the MRC method is similar to the method proposed here, the former takes heuristic steps with the aim of achieving high-speed re-routing in case of failure and the metrics calculation is based on the premises of bypass.

Furthermore, as for studies that use multi-topologies, the fewer the number of topologies is better from the viewpoint of route control complexity. Study [13] focuses on reducing the number of MRCs to be used. Considering that, we also treat the number of topologies as an important index in this paper.

In this paper, we explain how to calculate metrics by solving the dual problems of the LP Equation of TE in Section II, and propose a method and TE with multiple metrics in Section III. Section IV addresses a calculation method of multiple metrics (none of which use ECMP), and a simulation and its results. Examination and use of other metric are described in Section V and the conclusion is stated in Section VI.

II. TE AND METRICS AND TRAFFIC ACCOMMODATION PATHS THAT REALIZE TE

This section consists of II-A LP formulation of TE, II-B a method to calculate metrics that can be realized with shortest paths (called "optimized metrics" hereafter), II-C calculation of flows that realize TE optimization with minimization of metrics, and II-D branching of each flow.

A. Description as Network Problem Network Description and Formulation of TE s

Figure 1 shows a network model. Network *G(V,E)* is defined with node set *V* and link set *E* as shown follow.

i,j	nodes
(i,j)	directional link between node i and node j
c_{ij}	capacity of link (i,j)
k, K	each traffic demand and a set of traffic ($k \in K$)
d_k	bandwidth of traffic demand k
s_k, t_k	start node and target node of traffic k
X_{ij}^{k}	ratio of traffic k transmitting through link (i,j)
D_{ij}	delay of link (i,j)

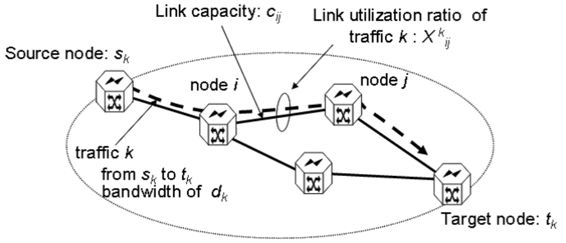

Fig. 1. Network Model.

Optimization with TE is a technology that distributes traffic within network and smoothes link utilization ratios. This can be realized by minimizing the congestion ratio, *α*, which is the largest value among the link utilization ratios.

The formulation is shown below [1].

$$\min \alpha \tag{1}$$

s.t.

$$\sum_{j:(i,j)\in E} X_{ij}^{k} - \sum_{j:(i,j)\in E} X_{ji}^{k} = \begin{cases} 1, & i = s_k \\ 0, & i \neq s_k, t_k \end{cases} \qquad \forall k \in K \tag{2}$$

$$\sum_{k\in K} d_k X_{ij}^{k} \leq \alpha c_{ij}, \quad \forall (i,j) \in E \tag{3}$$

$$\alpha \geq 0, \ 0 \leq X_{ij}^{k} \leq 1, \quad \forall k \in K, \ \forall (i,j) \in E \tag{4}$$

In equations (1) and (3), *α* is minimized under the condition that each link utilization ratio is α or smaller after dividing the total traffic volume, $\Sigma_{k\in K}\, d_k\, X_{ij}{}^k$, by c_{ij}. $\Sigma_{k\in K}\, d_k\, X_{ij}{}^k$ is the total amount of traffic flowing in link (i, j), the individual traffic flows are given by d_k. Calculation with TE brings out the congestion ratio, α, and traffic accommodating route $X_{ij}{}^k$ that realizes α. Equation (2) is the conservation law of flow, which implies that $X_{ij}{}^k$ is a variable that defines the flow route [14]. We do not describe the formulation that contains t_k here because it is redundant.

B. *Deriving optimized metrics*

The dual problems of Eqns. (1) to (4) are recast as (5) to (8). Solving these problems yields metrics that realize α_{TE} and thus the shortest paths[8].

$$\max \quad \sum_{k\in K} d_k U_{t_k}^k \qquad (5)$$

subject to:

$$U_j^k - U_i^k \le W_{ij} + r \;,\; \forall k\in K,\; \forall (i,j)\in E \qquad (6)$$

$$\sum_{(i,j)\in E} c_{ij} W_{ij} = 1 \qquad (7)$$

$$W_{ij} \ge 0\,,\; U_{s_k}^k = 0 \qquad (8)$$

Here, d_k, c_{ij} and r are given parameters and U_{ij} and W_{ij} are variables. In the right side of Eqn. (6), $W_{ij}+r$ is link cost as per the optimized metrics and is expressed as w_{ij}. The optimum routes obtained from Eqns. (1) to (4), can be reproduced as shortest paths based on positive link weights, w_{ij}.

C. *Standard path: Path that realizes TE (minimizes optimized metrics)*

α_{TE} can be realized with the shortest path where the metrics acquired from Equations (5) to (8) are used as link costs. A path where α_{TE} is realized with optimized metrics can be acquired with the following optimization (9) under the conditions of Equations (2) and (4).

$$\min \; \alpha + \sum_{k\in K} \sum_{(i,j)\in E} w_{ij} X_{ij}^k \qquad (9)$$

This path minimizes the optimized metrics and provides a path that realizes TE at the same time. We call this path the ″ standard paths. ″

D. *Branching into flows of standard path*

Each individual flow from $X_{ij}{}^k$ acquired in (9), which is defined by the path from the starting node to the ending node with no splitting, and the traffic volume that the path uses can be determined [15]. Focusing on single traffic flows, we write variable $X_{ij}{}^k$ as just X_{ij}. Consider the graph of link (i,j) of $X_{ij} \neq 0$ and nodes associated with the link. With this graph, find a single path by depth-first search, determine the minimum value of X_{ij} on the path as the volume of traffic that uses the path, and subtract the components associated with the flow from X_{ij}. Repeat this operation until X_{ij} becomes 0. We apply this operation to X_{ij} in (9) and obtain explicit paths of the standard paths. ・ Hereafter, we call thus obtained paths the standard paths.

III. PROPOSAL OF METRIC BASED TE THAT USES MULTIPLE COST SETS THAT DO NOT USE ECMP: MT-TE (MULTIPLE TOPOLOGY TE:)

A. *Proposed method*

The proposed method, MT-TE, transmits the flows identified in Section II by using shortest paths of multiple metrics that do not use ECMP. In this method, link cost setting, flow bandwidth provision, and transmission within a network are carried out as follows;

(1) The multiple link costs are defined for each link, and each link cost is identified by an ID.

(2) Metrics consist of link costs such that ECMP is not present on the shortest path.

(3) At the input node, traffic is provided as ratio of the traffic volume acquired by breaking down the solution of TE calculation into a flow.

(4) Path of each flow is identified by using the shortest path identified by the multiple metrics that do not use ECMP.

(5) Each flow is assigned the ID of the metric that identifies the path as being the shortest.

(6) Node device calculates the shortest path for each metric ID and enters them in the routing table.

(7) Node device carries out input flow routing according to the metric ID of the flow.

For (1), (6) and (7), the same method of MT-OSPF is used. (3) is carried out following the steps described in Section II-D. We describe the characteristic of the proposed method (2) and (4). We adapt (5) to the results of (2) and (4).

B. *Steps for deriving cost sets*

To realize (2) and (4) in Section III-A, set the shortest path as the standard path and search for cost sets that do not use ECMP. The proposed steps are as follows.

1) Add a minimal variable to each link cost of optimized metrics and set them as cost sets. The minimal variable is a random number set within the range given by the smallest value of each cost value that appears in the optimized metrics.

2) Calculate the shortest path with using the cost set in 1). Compare the shortest path and the standard path and each cost value of cost sets, store data associated with the standard path

that matches the shortest path while dropping the path that matches the shortest path from the set of standard paths. At this point, if no standard path remains, stop the processing.

3) Set the new standard path acquired in 2) as the standard path and return to 1).

In 1), cost values are changed by adding a minimal random number to the optimized metrics to prevent the appearance of ECMP. Thus, if the random number is changed a certain times, all paths will appear. In the operation of 2), it could be that none of the standard paths match the shortest path. If so, do not store the cost set because there is no meaning in realizing the standard path in this case.

Since random numbers are used in generating cost sets, results vary depending on the random number generated. Here, we generated 100 random numbers, and compared the number of paths that shortest paths created with each random number that matched the standard path and used the cost set with the greater number.

IV. SIMULATION

A. *Simulation conditions*

Table I shows the conditions used in the simulations. As for topologies, we used the real network model of cost239[16], nsfnet[17] shown in Figure 2 and topologies generated by the topology generator brite[18].[1] We used links with the same capacity. We used the traffic demands on a full mesh between each node, and randomly changed the distribution within the range of average ±20% and ±40% (only for real network model).

For cost239 and nsfnet, we generated 10 traffic distributions for each topology. As for the brite-generated topologies, we generated 10 kinds with 15 nodes and with 30 nodes using the same generation parameter and randomly generated traffic distributions.

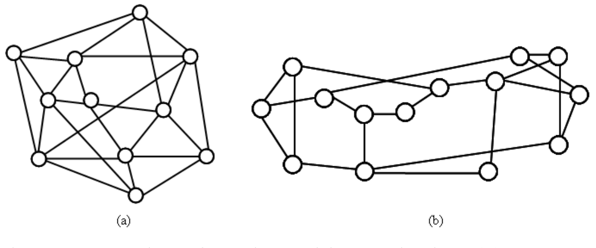

Fig. 2. Examples of Real World Topologies, (a) cost239, (b) nsfnet.

Table 1 Simulation conditions.

Topology:real network model	cost239, 11nodes, 25 edges nsfnet, 14 nodes, 21 edges
Topology: brite	15, 30 nodes, Waxman model Node to edge ratio: 2, 3
Traffic distribution	Average ± 20%, ± 40% (only for real network model)

B. *Simulation results: the number of cost sets*

Tables 2, 3 and 4, 5 show simulation results for cost239 and nsfnet topologies. In the tables, TM is the traffic matrix. Tables 2, 4 show the results when the range of changes of each element of TM is ±20%, while Tables 3, 5 shows the results when the range is ±40%. We created 10 sorts of TM and carried out 10 simulation trials on each. If we look at minimum values of the number of cost sets for each topology and each TM, it does not much depend on TM, the number of cost sets was 4 to 6 when the TM change range was 20% for cost239, while it was 4 to 7 when the range was 40%; it was 3 to 4 for nsfnet.

Table 2 The number of cost sets: cost239 with TM of ±20% change.

trial	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	5	5	6	5	6	4	5	5	5	4
2	6	4	6	6	6	5	5	5	5	5
3	6	5	6	6	6	4	5	5	4	4
4	5	4	6	4	6	4	5	6	4	5
5	7	5	5	5	6	4	4	5	4	5
6	5	5	6	5	6	5	5	5	5	5
7	6	5	6	5	7	5	5	6	6	5
8	5	4	5	5	6	4	5	6	5	5
9	5	4	5	5	6	5	5	6	6	4
10	5	5	6	5	6	5	4	6	5	4

Table 3 The number of cost sets: cost239 with TM of ±40% change.

trial	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	6	7	6	6	6	6	5	5	4	4
2	6	9	5	5	6	5	5	5	5	5
3	7	9	5	5	5	5	5	5	5	5
4	6	8	6	6	6	5	5	6	5	5
5	6	7	5	6	5	5	5	5	5	5
6	5	7	6	6	5	5	5	5	5	5
7	6	7	5	6	5	5	5	5	6	6
8	6	7	5	6	5	6	5	5	5	5
9	5	8	5	6	5	5	6	4	5	5
10	6	8	5	5	5	7	5	5	5	5

Table 4 The number of cost sets: nsfnet with TM of ±20% change.

trial	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	4	4	4	4	4	4	4	4	4	5
2	4	5	4	4	4	5	4	5	4	4
3	5	5	4	5	4	4	5	4	4	5

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[1] For each topology generated by brite, the number of links equals the number of nodes multiplied by the node to edge ratio.

4	4	4	5	4	5	4	5	4	5	4
5	5	4	5	5	4	4	5	4	4	5
6	5	4	4	5	3	5	4	4	4	4
7	4	4	4	4	4	4	4	5	5	5
8	4	4	5	5	3	4	4	4	4	4
9	4	5	5	4	4	4	4	4	5	5
10	5	5	4	5	3	4	5	5	4	5

Table 5 The number of cost sets: nsfnet with TM of ±40% change.

trial	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	5	3	4	4	4	4	4	4	5	4
2	4	3	5	4	5	4	5	4	4	4
3	5	3	5	5	4	4	4	4	4	4
4	4	4	4	4	4	5	4	4	5	4
5	4	4	4	4	3	4	4	5	4	4
6	4	3	5	5	4	4	4	5	4	4
7	5	3	5	5	5	3	4	4	4	4
8	3	3	5	4	5	4	5	5	4	4
9	5	4	4	4	4	5	4	4	4	4
10	5	4	4	4	4	4	4	4	5	4

Tables 6, 7 show the results for topologies generated with brite. We created 10 sorts of topology with the same generation parameter while TM is the average value of each element by ±20%. We created 10 sorts of TM and carried out 5 simulation trials on each.

Table 6 The number of cost sets: brite-generated model, 15 nodes.

(1) node-to-edge ratio=2

trial	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	6	5	5	4	6	4	5	7	5	6
2	6	5	5	5	7	4	5	6	5	6
3	7	5	5	5	6	4	5	6	5	5
4	5	5	6	5	6	4	6	7	6	5
5	5	5	5	4	7	6	5	7	5	5

(2) node-to-edge ratio=3.

trial	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	6	8	7	8	6	6	6	7	5	7
2	7	7	6	8	6	6	6	8	6	6
3	7	8	6	8	6	6	6	6	6	7
4	6	7	6	7	5	8	8	6	6	7
5	7	7	7	7	6	7	7	7	5	7

Table 7 The number of cost sets: brite-generated model 30 nodes.

(1) node-to-edge ratio=2.

trial	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	9	8	8	8	9	8	9	12	6	11
2	9	8	8	10	10	8	8	13	7	11
3	8	9	7	9	10	10	10	12	7	11
4	9	8	8	9	9	10	10	11	7	12
5	8	8	7	9	10	9	9	13	8	10

(2) node-to-edge ratio =3.

trial	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	9	9	5	9	12	8	8	8	8	9
2	10	8	6	9	14	9	8	7	7	10
3	10	8	6	8	13	8	8	8	8	8
4	9	9	5	9	12	9	7	9	8	8
5	9	9	6	8	13	8	8	8	8	9

The minimum values of the number of cost sets in each case were 4 to 6 for n15-2, 5 to 7 for n15-3. It was 8 to 11 for n30-2, 12 to 14 for n30-3. Here, brite-generated topology with 15 nodes, whose node-to-edge ratio was 2 was described as n15-2.

From the viewpoint of the relationship with the number of nodes, the number of cost sets was 1/3 to 1/2 the number of nodes for topologies other than cost239. In the case of cost239 with 11 nodes, the minimum number of cost sets was 6 and 7.

There is a possibility that fewer cost sets can be acquired if more trials are done. However, the change range is considered to be not large. We can see that the average range deviation is about ±1 in the calculation example given here.

C. *Simulation results: metric value range*

Table 8 shows the maximum and minimum cost values identified from the optimized metric calculations. In the table, c20, c40 are for cost239 with TM change ranges of 20% and 40% while n20, n40 are for nsfnet with TM change ranges of 20%,40%, respectively. And brite-generated topology with 15 nodes whose node-to-edge ratio was 2 was described as n15-2. The same notation was used for n15-3, n30-2, and n30-3. Values described in the table are maximum values under each topology condition normalized by the minimum value and their bits expressions are given in parentheses.

Random number range is 1/100 (6.64 bits) for the minimum cost value. Under the condition that the random number can be set only as a positive integer, the number of bits that must be set to identify the maximum cost value is about 17 to 18 bits.

Table 8 Ratio of the maximum versus minimum cost values.

c20	c40	n20	n40	n15-2	n15-3	n30-2	n30-3
626 (9.3)	626 (9.3)	501 (9.0)	502 (9.0)	1667 (10.7)	1668 (10.7)	1651 (10.69	1666 (10.7)

V. EXAMINATION AND USE OF OTHER METRIC

A. *Status of flow branching*

In the proposed method, each traffic is given an ID that designates the metric to be used by referring to the destination address at the input node. If the input traffic is branched and multiple flows are to be used, branching must be performed in accordance with the ratios acquired from the TE calculation. We examined how many traffic streams would require this processing. The distribution of the numbers of branched paths acquired through standard path calculation is shown in Tables 9 to 12. Tables 9,10 show the results for a real-world topology and Tables 11, 12 show the results for a brite-generated topology. As the tables show, the branching is not required for at least 73% of the traffic for cost239 and at least 94.5% of the traffic for nsfnet. As for the brite generated topology, branching is not required for at least 86.6% of the traffic when the number of nodes is 15, and 97% when the number of nodes is 30.

Table 9 Distribution of the number of traffic branching for cost239 with traffic change of (a) ±20% and (b) ±40%.

(a) ±20% traffic change.

Number of branch	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	86	86	85	83	87	83	84	83	83	86
2	21	22	22	24	20	25	25	25	26	22
3	2	2	2	3	2	2	1	2	1	1
4	1	0	1	0	0	0	0	0	0	1
5	0	0	0	0	5	0	0	0	0	0

(b) ±40% traffic change.

Number of branch	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	83	82	87	81	86	91	84	84	87	94
2	24	25	19	27	20	15	23	25	19	14
3	3	1	2	1	4	3	3	1	4	1
4	0	2	2	1	0	1	0	0	0	1

Table 10 Distribution of the number of traffic branching for nsfnet with traffic change of (a) ±20% and (b) ±40%.

(a) ±20% traffic change.

Number of branch	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	174	176	173	173	175	173	173	175	173	173
2	7	4	8	9	7	9	9	7	9	9
3	1	2	1	0	0	0	0	0	0	0

(b) ±40% traffic change.

Number of branch	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	172	175	176	174	175	176	176	174	173	176
2	9	5	6	8	7	6	6	4	9	6
3	1	0	0	0	0	0	0	0	0	0

Table 11 Distribution of the number of traffic branching for brite-generated topologies: 15 nodes with node to edge ratio of (a) 2 and (b) 3.

(a) node to edge ratio of 2.

Number of branch	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	189	197	197	199	199	197	201	192	198	194
2	19	13	13	11	9	13	8	15	12	16
3	2	0	0	0	2	0	1	3	0	0

(b) node to edge ratio of 3.

Number of branch	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	182	183	185	188	194	189	192	187	195	184
2	15	26	2	21	14	18	17	23	14	23
3	3	1	3	3	2	2	1	0	1	3
4	0	0	0	0	0	1	0	0	0	0

Table 12 Distribution of the number of traffic branching for brite-generated topologies: 30 nodes with node to edge ratio of (a) 2 and (b) 3.

(a) node to edge ratio of 2.

Number of branch	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	833	826	842	828	831	823	829	833	829	818
2	35	43	27	39	34	46	41	35	41	52
3	2	1	1	3	5	1	0	2	0	0

(b) node to edge ratio of 3.

Number of branch	No. of Topology									
	1	2	3	4	5	6	7	8	9	10
1	830	834	834	819	803	844	820	827	811	847
2	36	38	33	48	63	26	49	40	56	21
3	4	2	3	3	3	0	1	2	3	2
4	0	0	0	0	1	0	0	1	0	0

As mentioned in Section VI-B, in most cases, the number of cost sets is about a half the number of nodes. When traffic is branched, since multiple paths are to be set as shortest paths between the same starting and ending node, two or more cost sets are required. From this point of view, the maximum value of the branching number gives a lower bound to the number of cost sets. From this aspect, the number of cost sets was double or lower for cost239, nsfnet, while the number was three to four times or lower for the brite generated model. For each case of cost239 TM changing range of 20% and nsfnet TM changing range of 40%, there were cases in which the number of cost sets equaled the branching number (TM No.10 and 1, respectively).

B. Adaption to metrics other than optimized metrics

Our proposed method can be used if TE and other effects are realized by branching with ECMP even if the costs are not those of optimized metrics. In order to consider such link costs, we describe the types of costs that are associated with optimized metrics. Table 13 shows different types of link cost values acquired through optimized metric calculations in the cases of cost239 and nsfnet. The number of existing directional links is 50 for cost239 and 42 for nsfnet. However, from the table, we can see that the difference among link cost values is 11 at most for cot239 and 6 for nsfnet. In particular, when the TM change range is 20% with cost239, the difference in the value of link costs is as small as 2. When this link cost is used, we can consider that it is close to the case when link costs are even. Therefore, here, we used metrics that assign the same value to each link's link cost, 1. This is the same as the number of hops is set as metrics.

Table 13 the kind of link cost: cost239.

.	No. of TM									
	1	2	3	4	5	6	7	8	9	10
20%	2	2	2	2	2	2	2	2	2	2
40%	7	11	2	7	8	2	3	2	2	2

Table 14 the kind of link cost: nsfnet.

.	No of TM									
	1	2	3	4	5	6	7	8	9	10
20%	6	4	6	6	5	6	5	4	6	6
40%	6	4	4	5	5	6	5	5	5	5

In the calculations, we acquired the standard path in the same way as for the optimized metrics, and acquired multiple cost sets from the number of hops. As for the standard path, we used the number of hops as the standard metric, and calculated Eqn. (9). At this point, we calculated the standard path, weighting to make the term of the minimum number of hops (the 2nd part of Eqn. (9)) greater than the term of TE (1st part of Eqn. (9)). α from this calculation is shown in Table 15. The values in Table 12 are the ratio of α when α is TE optimized. Table 15 lists the results for cost239 and nsfnet, and we can see values that coincide when TE calculation is carried out without considering the number of hops and the TM change range is 20% with cost239. In this case, traffic that matches TE results can be accommodated even if we set the number of hops as the metrics, i.e. optimized metrics are not used. For the cases of cost239's TM change range of 40% and nsfnet, α is degraded 3.7% to 12% compared to the case of TE.

Table 15 Congesion ratio of TE under the condition of HOP number minimization, compation to only TE calculation.

c20	c40	n20	n40
1.000	1.037	1.105	1.120

Next, Table 16 shows results when the number of cost sets was calculated by using the number of hops as metrics for the case of TM change range of 20% with cost239. In this case as well, we can see that about the same number of cost sets was acquired as in Table 2.

Table 16 The number of cost sets with metric of HOP count: cost239 with TM of ±20% change.

trial	No. of TM									
	1	2	3	4	5	6	7	8	9	10
1	5	6	5	5	5	5	5	5	4	5
2	5	5	5	6	4	5	5	5	5	5
3	5	5	5	5	5	5	5	4	5	5
4	6	6	5	6	5	5	5	5	5	5
5	5	5	5	5	6	6	6	4	5	5
6	5	6	7	5	5	5	5	5	5	4
7	5	5	6	5	5	5	5	5	5	4
8	5	5	6	6	6	5	5	5	5	5
9	5	5	5	6	5	5	6	6	5	5
10	5	6	5	6	5	5	4	6	6	4

VI. CONCLUSION

In order to simplify the routing that realizes TE, we proposed a metric-based TE realization method (MT-TE) that supports multiple topologies. In our proposed method, we used multiple metrics within a network and multiple topologies acquired with the shortest path for each metric. Traffic is to be branched into one or more flows at the point of input, and routing is carried out with the shortest path using the metrics that correspond to the given ID. Path to be realized is a TE path, and we can realize convergence rates that are optimized for TE by utilizing the bandwidth acquired through LP calculation of each flow. In this method, each individual flow to realize TE is determined by using the shortest path identified by the multiple metrics that do not use ECMP Therefore, route setting within a network is relatively easy. We showed a calculation method to acquire cost sets, groups of link costs for each metric, by using random numbers from optimized metrics that realize TE. The required number of cost sets calculated with the method did not exceed 1/2 to 1/3 the number of nodes in most cases. As for full mesh traffic where the number of flows is of the order of n^2, smaller values were acquired compared to the number of paths, and we demonstrated that we can expect smaller route setting scale.

VII. ACKNOWLEDGEMENT

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