Traffic Engineering for Peer Model Multilayer Network and Its Application to Topology Simplification

Masashi Hashimoto and Koko Sasamura

Abstract—**We study TE (traffic engineering) for the peer model multi-layer network. In the peer model, information of each layer can be advertised. By introducing a mechanism that allows the lower layer to refer to information from the upper layer, we derive an LP formulation for multi-layer traffic engineering. Using this formulation, we consider the optimization of both layers at the same time. Simulation results show that this approach is superior to optimizing the layers in isolation. Moreover, in many cases, the optimized value is confirmed to be valid as it is very close to the value indicated by single layer optimization. In addition, we study topology design considering multilayer configuration with proposed method. We show how the interdependency of the layers can simplify the lower layer topology without metric degradation. By simulation, multilayer topology with a simplified lower layer is successfully obtained.**

Index Terms—**Multi-layer, peer model, traffic engineering.**

I. Introduction

WITH the greater spread and accessibility of IP phones and broadband services, the penetration of backbone networks is continuing to increase. The vast amount of IP layer (logical layer, hereafter upper layer) traffic is usually accommodated by optical networks (optical or optical path layer, hereafter lower layer) such as WDM optical networks. Those optical IP networks deploy a multi-layer architecture. There are two management approaches: the peer model and the overlay model [1]. The peer model supports an integrated routing approach, which means that topology and resource information in the both upper and lower layers can be referred and controlled in an integrated manner. On the other hand, the overlay model controls information in the upper and lower layers independently. The lower layer receives requests to establish optical paths from the upper layer through [2] and carries out route setting.

With the goal of realizing service networks based on GMPLS [3]-[4] , proposals and studies been made on multi-layer service networks that deploy a structure that collects/informs information on multi layers and implements a routing protocol [5], [6].

In this paper, we focus on the peer model. Since the model supports an integrated routing approach, overall optimization is expected to be achieved, but the characteristic policies of each layer may not be achieved. There are two major routing policies. One is to use the minimum cost defined on the network such as the minimum number of HOPs and the minimum delay routing. The other is to use routes that avoid traffic concentration on particular links.

In this study, we describe the peer model multilayer network with Linear Programming (LP) and treat metrics from both layers in an integrated manner. We include metrics of both layers in the target functions for simultaneous optimization to improve the considered metrics on each layer at the same time. We also consider a method of reducing the number of routes in order to simplify lower layer topologies. In the method, we keep the routing policy and delete as many routes as many as possible provide convergence is not disturbed. Using the above method allows us to enhance effectiveness when metrics on both layers are considered simultaneously in two cases; when both layers have the same topology and when the topologies diverge after route reduction.

This paper is organized as follows. In section II, the formulations of peer model multilayer network and its metrics are described. Section III and IV show simulation conditions and results of metric optimization in both layers, respectively. In section V, we introduce topology design method of the lower layer and in section VI, its example results are shown. Finally, section VII concludes this study.

II. Network model

A. Description as Network Problems

Logical links in the upper layer are to be established on optical paths in the lower layer. As Figure 1 shows, node locations are the same in both layers. This means all nodes in the lower layer also exist in the upper layer, but links are not the same. For example, the logical link from node 2 to node 5 is defined as the path B→A→C→E. Connections between nodes in the upper layer are established on paths that consist of one or multiple links in the lower layer. This topology information can

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be transmitted between layers and treated in an integrated manner. On the other hand, traffic is defined between nodes in the upper layer. As this traffic is carried by the lower layer, we address here the topology and metrics needed to utilize the capacity of the lower layer.

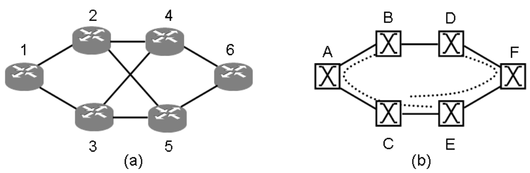

Fig. 1. Links in (a) the upper layer and (b) paths in the lower layer.

The following is a description of LP network problems for upper layer.

- E_u node set
- i,j each node
- L_u link set
- (i,j) link from node i to node j
- hop_{ij} HOP count between node i and node j. [1]
- k, K traffic identifier and traffic set
- d_k each traffic demand
- s_k, t_k source node and destination node of traffic d_k
- X_{ij}^k the proportion of link (i,j) in traffic d_k
- u_{ij} capacity of link (i,j)
- α_{u_max} the maximum value of link utilization ratio in all links

Restrictions in the upper layer are related to the requirements of network flows[7], [8], utilization ratio, and bandwidth of network flow.

[Network conservation law]
subject to

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

$$\forall k \in K \quad (1)$$

[Link utilization ratio restriction]
subject to

$$\sum_{k\in K} d_k X_{ij}^k \leq \alpha_{u\_max} u_{ij}, \quad \forall (i,j)\in L_u \quad (2)$$

[Requirements for variable X_{ij}^k]
subject to

$$0 \leq X_{ij}^k \leq 1, \ \forall k \in K, \ \forall (i,j)\in L_u \quad (3)$$

The lower layer is defined as follows

- E_l node set
- q, r each node
- L_l optical link set
- (q,r) optical link from node q to node r
- l_{qr} capacity of link (q,r)
- α_{l_max} the maximum value of link utilization ratio in all links
- $cost_{qr}$ cost, delay, price, credibility and others defined by link (q,r)
- X_{qr}^k the proportion of link (q,r) traffic d_k

Traffic is not defined in the lower layer because traffic is input to the upper layer. We consider using shortest routes with indexes such as delay and credibility in selecting paths in the lower layer and assign them to paths by defining link COST ($cost_{qr}$) on each link.

In peer model description, resources in both the upper and lower layers can be are considered at the same time. For example, the structure of the upper layer is given by defining one or multiple links of the lower layer that construct links in the upper layer [9]. Implement parameter P_{ijqr} which tells if the lower layer's link (q,r) is included in link (i,j).

- P_{ijqr} parameters which show (i,j) includes link (q,r) (=1) or not (=0)

On the lower layer, we can also consider X_{qr}^k of the lower layer which means the proportion of link (q,r) in traffic d_k. However, X_{qr}^k is not independent variable. We can only consider X_{qr}^k as a parameter which is defined as the one that corresponds to X_{ij}^k of the upper layer. Relations between them are described below.

$$X_{qr}^k = \sum_{(i,j)\in L_u} P_{ijqr} X_{ij}^k, \ \forall k \in K, \ \forall (q,r)\in L_l \quad (4)$$

The restrictions set for the upper layer can be considered for the lower layer. However, the conservation law for the upper layer P_{ijqr} is to be modified for the lower layer. Bandwidth requirements are also re-written for the lower layer since each traffic flow is transmitted through paths in the lower layer. Thus, the following equation is equivalent to equation (2).

$$\sum_{k\in K} \sum_{(i,j)\in L_u} d_k P_{ijqr} X_{ij}^k \leq \alpha_{l\_max} l_{qr}, \quad \forall (q,r)\in L_l \quad (5)$$

B. Target Function for Optimization

As for metrics addressed in each layer, metric optimization can be done for the upper layer, the lower layer, or a combination of both. In the first two methods, when one is optimized, the other is not optimized and optimization values will be worse than if the layer were optimized by itself. In the third method, on the other hand, neither layer will have the ultimate "best" values, but both layers will exhibit some degree of optimization. In this section, we examine the three methods of optimization.

[1] When a link from node i to node j exists, hop_{ij} is 1, otherwise not defined.

C. *Optimization of Metrics in The Upper Layer*

As the target functions in the upper layer, we used minimization of the HOP count and minimization of the maximum link usage rate, in other words TE [10], [11].

Each are described as follows

＜Target function for minimization of the Hop count＞

$$\min \sum_{k\in K}\sum_{(i,j)\in L_u} hop_{ij} X_{ij}^k \quad (6)$$

＜Target function for minimization of the maximum link utilization ratio＞

$$\min \quad \alpha_{u\_max} \quad (7)$$

The maximum utilization ratio, α_{u_max}, is an index for smoothing traffic. The smaller the number is, the better traffic can be distributed and accommodated.

D. *Optimization of Metrics in the Lower Layer*

While we could have used the HOP count as above, we used COST as defined by links.

＜Target function for minimization of COST＞

$$\min \sum_{k\in K}\sum_{(q,r)\in L_l} cost_{qr} X_{qr}^k \quad (8)$$

＜Target function for minimization of the maximum link utilization ratio＞

$$\min \quad \alpha_{l\_max} \quad (9)$$

E. *Optimization of Metrics in Both Layers*

Equations (6) to (9) are for layer optimization in isolation. Our solution is a target function that considers both layers. When the target functions for the upper and lower layers are object1 and object2, respectively, both functions are linear against variable X_{ij}^k. Therefore, the combination of object1 and object2 is also a linear function. We implement optimization by using this combination as the target function. For example, we use upper layer metric of HOP count and lower layer metric of α_{l_max}.

Table 1

Compound metric in multilayer network.

Metric		
Upper layer	Lower layer	
HOP count	COST	$\sum_{k\in K}\sum_{(i,j)\in L_u}(hop_{ij}X_{ij} + cost_{ij}P_{ijqr}X_{ij}^k)$
HOP count	utilization	$\sum_{k\in K}\sum_{(i,j)\in L_u} hop_{ij}X_{ij}^k + \alpha_{l\_max}$
utilization	COST	$\alpha_{u\_max} + \sum_{k\in K}\sum_{(i,j)\in L_u} cost_{ij}P_{ijqr}X_{ij}^k$
utilization	utilization	$\alpha_{u\_max} + \alpha_{l\_max}$

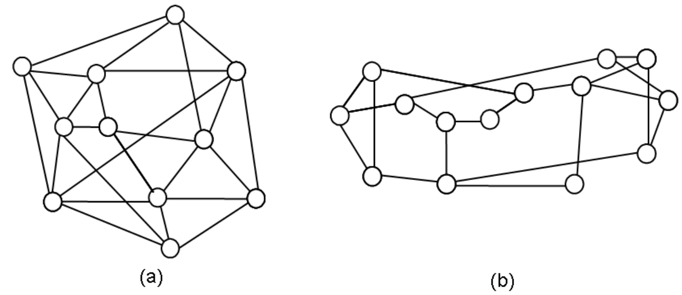

Fig. 2 Network topologies: (a) COST239 (11nodes, 25 links) and NSFNET (14 nodes, 21 links).

We examined the combinations shown in Table 1 and considered combinations of HOP count for the upper layer and COST for the lower layer as well as the maximum link utilization ratio in each layer. Since target functions are linear, we use the sum of both layers as the new target functions. We wrote table formulas for the sum of each minimization index for the target functions in the table. However, the order of items (for example, the Hop count and COST) can be different, so we multiplied a certain constant number to make it same order when we actually calculated. With this method, we aim to lower (optimize) both indexes at the same time.

III. SIMULATION CONDITIONS

A. *Topologies*

We used the network topologies shown in Figure 2. COST239 is the European model [12], NSFNET is the North American model [13]. Nodes correspond to actual cities. Here, we set the same topologies in the upper and lower layers and each link is bi-directional with identical capacity.

B. *Traffic and COST*

Traffic is full-mesh two-way traffic. There are various traffic distribution models [14] that determine each traffic value. Our simulations used the three kinds of traffic shown in Table 2. Traffic1 is traffic that is proportional to population and inversely proportional to distance between starting and ending nodes. Traffic2 is traffic that is proportional to population between starting and ending nodes. Traffic3 is uniform traffic, i.e. all the same. As for COST, it is the HOP count in the upper layer and delay in the lower layer, and we set values of delay that are proportional to distance between cities.

Table 2

Traffic distribution model.

traffic	definition
traffic1	proportional to P_iP_j / D_{ij}
traffic2	proportional to P_iP_j
traffic3	uniform

P_i: population of city i. D_{ij}: distance between cities i and j.

IV. Simulation results

Table 3 (for COST239) and Table 4 (for NSFNET) show the results for metric optimization by referring to the multi-layer framework for both layers. Those tables show normalized values, value of both layer optimization divided by the corresponding value for single layer optimization. The closer the value is to 1, the closer the value is to the best value that is optimized for both layer.

Table 3
Optimization by compound metric: COST239.

layer	metric	traffic 1	traffic 2	traffic 3
upper	HOP	1.01	1.00	1.00
	count	(1.33)	(1.31)	(1.08)
lower	α_{l_max}	1.00	1.00	1.02
		(2.35)	(2.17)	(1.80)
upper	HOP	1.02	1.02	1.02
	count	(1.20)	(1.20)	(1.20)
lower	delay	1.07	1.07	1.07
		(1.28)	(1.33)	(1.29)
upper	α_{u_max}	1.01	1.01	1.03
		(2.29)	(3.32)	(3.20)
lower	delay	1.01	1.01	1.03
		(2.29)	(3.32)	(1.34)

Table 4
Optimization by compound metric: NSFNET.

layer	metric	traffic 1	traffic 2	traffic 3
upper	HOP	1.02	1.00	1.01
	count	(1.19)	(1.15)	(1.17)
lower	α_{l_max}	1.05	1.01	1.02
		(2.27)	(2.12)	(1.22)
upper	HOP	1.05	1.05	1.05
	count	(1.07)	(1.07)	(1.07)
lower	delay	1.01	1.01	1.01
		(1.12)	(1.12)	(1.12)
upper	α_{u_max}	1.09	1.00	1.14
		(2.56)	(2.21)	(1.88)
lower	delay	1.07	1.03	1.04
		(1.40)	(1.33)	(1.25)

In those tables, values in parenthesis are the values of target function when optimization is carried out for one layer without considering the metrics of the other layer. If a value is smaller than the value in parenthesis, optimization on both layers is effective. Since the topologies of the upper/lower layer are the same, the tables do not include the maximum link usage rates of α_{max1} in the upper layer or α_{max2} in the lower layer because they are the same.

Table 3 suggests that when optimization is carried out at one layer independently, the difference in value from the other layer can be significant, 3.32 times. On the other hand, when optimization is carried out at both layers at the same time, the highest value only a 7% increase compared to optimization at one layer. Results in Table 4 are almost the same. The maximum difference was 2.56 times higher with a 14% increase. Other than this highest value, the other values exhibited only a 9% increase. These results confirm the effectiveness of the proposed framework.

V. Examination of applying the lower layer topology configuration method

A. Configuration procedure

In the previous section, both layers used the same topology. In reality, however, they may be different. Thus, we examined a method of setting up the lower layer. We started with identical topologies in both layers and then deleted paths until one or more conditions were satisfied. Under the assumption that shortest routes are to be used, we deleted as many paths as possible provided the maximum link utilization ratio in the lower layer did not change.

1) Flow traffic from the upper layer to the lower layer with the default topology. Assume the lower layer and setup path to be the shortest route in the lower layer, which means links in the upper layer should be set up on the shortest route path.
2) Determine which links should be deleted among paths in 1). If paths can be deleted, return to 1). If there is no links that can be deleted, finish.

If after path deletion a topology satisfies the following condition it can be deleted. Here, deleting a link deletes links in both directions.

1) Topologies are connected.
2) The maximum link utilization ratio is the same value as in the default topology or lower.

Topologies acquired through the above steps keep the rule that the lower layer always takes the shortest route in route setting and also have the characteristic that deletion does not make the congestion ratio worse. At the same time, links in the lower layer that support paths in the upper layer can be defined.

B. Implementation example of topology results

Figure 3 shows an example of a topology yielded by the above method. This is an example of COST239, traffic1. The links indicated by dotted-lines are deleted links. In this case, 11 out of 25 two-way links could be deleted. When 12 links were deleted, the maximum link utilization ratio in the lower layer exceeded that of the default topology. Table 5 shows that the logical topology in the upper layer did not changed with deletion. This result shows that the proposed method makes it possible to acquire the lower layer path architecture that accommodates the lower layer topology while supporting the links in the upper layer.

Table 6 shows the number of links that could be deleted from the default topology . In this results, COST239 topology had more links that could be deleted. So, it can be said that the average node order is high and has greater flexibility as a network topology. It also tended to have a greater degree of link deletion for traffic1 and traffic2 that have stronger randomicity.

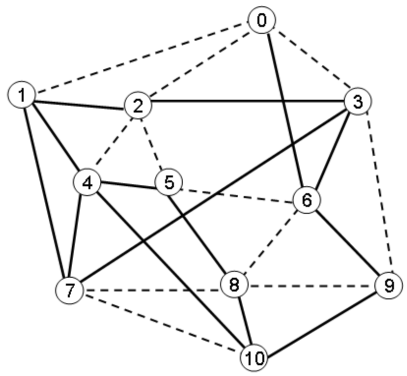

Fig. 3 Example of lower layer design.

Table 5
Example of lower layer design.

upper layer link	path through lower layer	upper layer link	path through lower layer
0 ⇔ 1	0-6-3-2-1	5 ⇔ 6	5-8-10-9-6
0 ⇔ 2	0-6-3-2	6 ⇔ 8	6-9-10-8
0 ⇔ 3	0-6-3	7 ⇔ 8	7-4-5-8
2 ⇔ 4	2-1-4	7 ⇔ 10	7-4-10
2 ⇔ 5	2-1-4-5	8 ⇔ 9	8-10-9
3 ⇔ 9	3-6-9	-	-

Table 6
Number of eliminated links.

	COST239	NSFNET
traffic 1	11	6
traffic 2	13	5
traffic 3	4	4

VI. MULTI-LAYER METRICS ON DIFFERENT TOPOLOGIES IN UPPER/LOWER LAYERS

In the above described simulation, we set the requirement that both layers had the same topology. However hereafter, we examine the topologies acquired from the above steps. That means the number of links shown in Table 6 was reduced from the original topology. Table 7 and Table 8 show the simulation results with use of the altered topology.

From Table 7, when optimization is carried out at each layer independently, the value can reach 3.8 times greater than that in the other layer. With the proposed method, however, the highest increase is only 33%. Other than the three examples with highest values, metrics in both layers increased by no more than 7% compared to the values acquired by optimizing each layer independently. Table 8 shows almost the same results. The maximum value was 3.03 times higher under single layer optimization but the increase was only 50% increase at most when both layers were optimized. 75% of the metrics in both layers exhibited only a 10% increase compared to those in a single layer. As the results show, even if the upper and lower layers have different topologies, we were able to acquire favorable results. However, we could not acquire values close to those listed in Table 3 and Table 4. This is attributed a drop in the flexibility of links.

Table 7
Effect of compound metric in multilayer network(2): COST239.

layer	metric	traffic 1	traffic 2	traffic 3
upper	HOP count	1.03 (1.35)	1.02 (1.35)	1.03 (1.11)
lower	α_{max2}	1.03 (1.69)	1.00 (1.66)	1.00 (2.60)
upper	HOP count	1.03 (1.11)	1.06 (1.22)	1.03 (1.04)
lower	delay	1.01 (1.23)	1.02 (1.24)	1.04 (1.24)
upper	α_{max1}	1.00 (1.86)	1.01 (2.40)	1.07 (3.20)
lower	delay	1.04 (2.15)	1.04 (1.69)	1.19 (1.31)
upper	α_{max1}	1.33 (1.38)	1.06 (1.62)	1.33 (1.33)
lower	α_{max2}	1.02 (3.80)	1.06 (1.75)	1.00 (2.25)

Table 8
Effect of compound metric in multilayer network(2): NSFNET.

layer	metric	traffic 1	traffic 2	traffic 3
upper	HOP count	1.03 (1.34)	1.07 (1.31)	1.04 (1.21)
lower	α_{max2}	1.02 (1.51)	1.01 (1.94)	1.00 (1.45)
upper	HOP count	1.15 (1.27)	1.16 (1.21)	1.12 (1.16)
lower	delay	1.01 (1.23)	1.01 (1.24)	1.01 (1.32)
upper	α_{max1}	1.05 (2.52)	1.05 (1.73)	1.39 (1.88)
lower	delay	1.09 (1.53)	1.03 (1.60)	1.03 (1.63)
upper	α_{max1}	1.50 (1.50)	1.09 (1.10)	1.22 (1.35)
lower	α_{max2}	1.00 (2.14)	1.01 (3.03)	1.09 (1.78)

VII. Conclusion

In this paper, we formulated a TE method that considers evaluation metrics in both upper and lower layers at the same time with LP in the peer model for multi-layer networks. The proposed model defines topologies of the upper layer and treats information in both layers in an integrated manner by describing the relationship that links in the upper layer are accommodated by paths in the lower layer. As the target functions, we used metrics considered in both layers. With the formulation, we showed an example of changing the topology by focusing on metrics in the lower layer when traffic flows from the upper layer. We considered optimizing the metrics in both layers at the same time, as well as the metrics the layers separately. Our results confirmed the effectiveness of optimizing the metrics in both layers at the same time. In most cases, we had favorable results since the deviation in the values achieved when optimization was performed on a single layer was relatively minor, at no more than 10%. This paper also shows that proposed method is useful for topology design considering multilayer configuration. With this method, simulation result shows that the lower layer topology can be simplified without metric degradation of both layers.

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