Multi-Layer Network Topology Design for Large-Scale Network

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***Abstract*—In this paper, we investigate the effectiveness of the conventional heuristic routing method that improves the computation time of MILP for the large-scale IP-optical network design and we propose a more effective heuristic routing method. The results of calculation experiments showed that proposed heuristic routing method is very excellent not only in the reduction of the computation time but also the accuracy of computation results.**

***Index Terms*—Network Virtualization, Design,Routing, MILP**

I. INTRODUCTION

Multi-layer networking (MLN) is considered as the future carrier backbone network [1]. In MLN, the logical topology is composed of lambda paths. Therefore, network operators should consider following MLN topology design problem; both the lambda routing on the physical topology and the IP routing on the logical topology.

The multi-layer routing problem is solved by computing the Mixed Integer Linear Programming (MILP) [2]. In this MILP problems, each variable means lambda-layer routing or the IP-layer routing and the number of variables is proportional to the forth power of the number of network nodes. Therefore, this MILP problem uses too much variables to be computated in practical time in such a large-scale network with a few hundred nodes.

As the conventional study for this issue, F. Ricciato et al. showed two heuristic proposals, one was the space-reduction method and the other was decomposition method [2]. The former method reduced variables by excluding guessable lambda-layer routing variables and the latter is that the overall resolution process goes through the iterative resolution of smaller sub-problems in relation to IP routing variables. However, their study had no evaluation about the effectiveness of each proposal. That is, the concrete computation time and the accuracy of computation value by using each heuristic method was not shown.

In this paper, we investigate the effectiveness of the original space-reduction and decomposition methods, and we propose a more effective space-reduction heuristic method.

II. FORMULATION OF MULTI-LAYER ROUTING

In this section, we formulate the multi-layer routing problem. Eq.(1)-(13) formulate the MILP of the multi-layer routing problem. Eq.(7)-(13) are newly formulated for the lambda path layer in this paper. In this MILP, we assume that routers have OXC function. Eq.(1) is the objective function of the MILP, which intends to minimize the number of router IP ports and OXC lambda ports. Eq.(2), (3) and (4) are flow conservation laws. Eq.(5) represents bandwidth constraints for logical links. Eq.(6) is a routing (packet forwarding) capacity constraint for each router. Eq.(7) and (8) are the constraints for the number of input and output ports in routers, respectively. Eq.(9) and (10) are the constraints of the number of wavelengths at starting point and terminating point of lambda path at routers, respectively. Eq.(11) is the conservation law of the number of wavelengths in core OXCs. Eq.(12) is the constraint of the number of lambda paths between OXCs. Eq.(13) is the constraint of the number of wavelengths at output ports in OXCs.

Variables:
$r^{s,d}_{i,j}$: traffic ratio from router $s \in Q$ to router $d \in Q$ using logical link from router $i \in Q$ to router $j \in Q$ $(0 \leq r^{s,d}_{i,j} \leq 1)$
$\lambda^{i,j}$: the number of lambda paths from router $i \in Q$ to router $j \in Q$ $(\lambda^{i,j} \geq 0)$
$\lambda^{i,j}_{m,n}$: the number of lambda paths using physical link from OXC $m \in Q$ to OXC $n \in Q$ within the lambda path from router $i \in Q$ to router $j \in Q$ $(\lambda^{i,j}_{m,n} \geq 0)$

Constants:
Q : set of nodes which include OXCs and routers
$t^{s,d}$: offered traffic volume from router $s \in Q$ to router $d \in Q$
B : bandwidth of logical link
G_i : routing (packet forwarding) capacity of router $i \in Q$
R_i : the number of ports of router $i \in Q$
$P_{m,n}$: the number of wavelengths in the physical link from OXC $m \in Q$ to OXC $n \in Q$
O_n : the number of wavelengths at output ports of OXC $n \in Q$
α : cost ratio of router port to OXC port

$$min \quad \sum_{i,j \in Q} \lambda_{ij} + \alpha \sum_{i,j,m,n \in Q} \lambda^{i,j}_{m,n} \tag{1}$$

$$s.t. \quad \sum_{j \in Q} r^{s,d}_{s,j} - \sum_{i \in Q} r^{s,d}_{i,s} = 1 \quad s, d \in Q \tag{2}$$

$$\sum_{i \in Q} r^{s,d}_{i,d} - \sum_{j \in Q} r^{s,d}_{d,j} = 1 \quad s, d \in Q \tag{3}$$

$$\sum_{i \in Q} r^{s,d}_{i,k} - \sum_{j \in Q} r^{s,d}_{k,j} = 0 \quad k, s, d \in Q \ (k \neq s, d) \tag{4}$$

$$\sum_{s,d \in Q} t^{s,d} \, r^{s,d}_{i,j} \leq B \, \lambda^{i,j} \quad i, j \in Q \tag{5}$$

$$\sum_{s,d,i \in Q} t^{s,d} \, r^{s,d}_{i,j} \leq G_j \quad j \in Q \tag{6}$$

$$\sum_{j \in Q} \lambda^{i,j} \leq R_i \quad i \in Q \tag{7}$$

$$\sum_{i \in Q} \lambda^{i,j} \leq R_j \quad j \in Q \tag{8}$$

$$\sum_{n \in Q} \lambda^{i,j}_{i,n} = \lambda^{i,j} \quad i, j \in Q \tag{9}$$

$$\sum_{m \in Q} \lambda^{i,j}_{m,j} = \lambda^{i,j} \quad i, j \in Q \tag{10}$$

$$\sum_{m \in Q} \lambda^{i,j}_{m,l} = \sum_{n \in Q} \lambda^{i,j}_{l,n} \quad i, j \in Q \ (l \neq m, n) \tag{11}$$

$$\sum_{i,j \in Q} \lambda^{i,j}_{m,n} \leq P_{m,n} \quad m, n \in Q \tag{12}$$

$$\sum_{i,j,m \in Q} \lambda^{i,j}_{m,n} \leq O_n \quad n \in Q \tag{13}$$

III. ORIGINAL VARIABLE REDUCTION METHOD

This section outlines the original space-reduction method and decomposition method. Refer to [2] for details.

A. Space-Reduction Method

The key idea of space-reduction method is the exclusion of lambda path candidates, which have much more physical link

978-0-9836283-0-9

This paper was peer reviewed by subject matter experts for publication in the Proceedings of ITC 2011

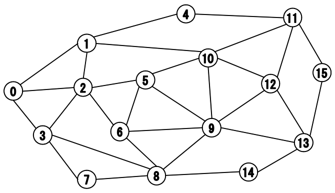

Fig. 1. Evaluation topology

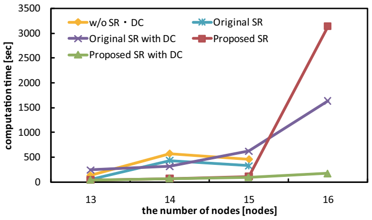

Fig. 2. Computation time

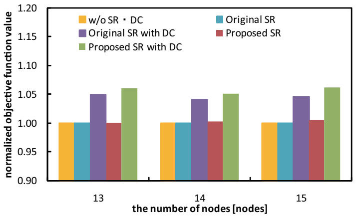

Fig. 3. Normalized objective function value

hops compared with that of the shortest path. First, we set the L_{max}, which is the maximum number of physical link hops between routers to be allowed. We also set the N_{max}, which is the number of candidates of lambda paths. Then, variables $\lambda_{m,n}^{i,j}$ except those using in the candidate lambda paths are set to 0 before MILP calculations. That is, since such variables are no longer variables, the number of variables can be reduced. Note space-reduction method cannot be applied to IP routing variables because the IP routing is independent to the lambda routing.

B. *Decomposition*

At first, the set of traffic flows between edge nodes $t^{s,d}$ are ordered in descending order, and all the routing variables $r_{i,j}^{s,d}$ are set to 0. At first step of iterations, the most bigger X traffic flows are set to $t^{s,d}$ and the other traffic flows are set to 0. At the nth step, traffic flows from the first bigger to the nth bigger X ones are set to $t^{s,d}$ and the other traffic flows are set to 0. At each iteration, the values of the $r_{i,j}^{s,d}$ calculated at the previous step are used and kept fixed. Since only the routing variables $r_{i,j}^{s,d}$ become valuables for the newly selected X traffic flows $t^{s,d}$, the number of variables can be drastically reduced.

IV. PROPOSED VARIABLE REDUCTION METHOD

In this section, we propose a new space-reduction method. The key idea of the proposal is the exclusion of lambda path candidates, which have longer physical link hops than the preassigned values. In our proposal, in some case, we may not establish a lambda path between routers. In such a case, we connect those routers using plural lambda paths. On the other hand, the original variable reduction method has at least one candidate lambda path between any routers. First, we set the $M_{L_{sp}}$, which is the allowed physical link hops for candidate lambda paths. Then, variables $\lambda_{m,n}^{i,j}$ except those using in the candidate lambda paths are set to 0 before MILP calculations.

V. PERFORMANCE EVALUATION

In this section, we evaluate the original and proposed methods from the viewpoints of computation time and effectiveness. We use CPLEX [3] to solve MILP. In our evaluations, we use 16 nodes network topology(Fig.1), which is extended topology of the reference [2]. We also assume the following conditions: B = 100Mbps, $t^{s,d}$ = 50Mbps, G_i = 1.5Gbps, R_i = 32, $P_{m,n}$ = 32, O_n = 32, α = 1, $M_{L_{sp}}$ = 3, X = 40. L_{max} and N_{max} are set to same values in the reference [2]. Because values of $t^{s,d}$ are same in our calculation experiments, the set X of traffic flows in the decomposition method are selected by using the order of node IDs.

Figure 2 shows the results of computation time. The notation of SR and DC in Fig. 2 shows whether SR(Space-Reduction) and DC(Decomposition) are applied or not. We were able to solve all methods in case of 13, 14 and 15 nodes. However, in case of 16 nodes, we couldn't solve w/o SR·DC and original SR after 5 hours computation by Dell PowerEdge R900 (CPU:Xeon X7460 × 4, memory:128GB) The computation times of the original SR with DC are longer than those of original SR in case of 13 and 15 nodes. The reason is as follows: when using CPLEX, two processes, that is, MILP loading process and computation execution process, are required. In case of original SR with DC, the former is longer than the latter. Due to this, the total computation time of original SR with DC becomes longer. As the same reason with this, the difference of the computation time between the proposed SR and the proposed SR with DC becomes little. However, in case of 16 nodes, the computation time of the proposed SR with DC becomes the shortest among all methods described in this paper due to the reduction of valuables by the decomposition method.

Figure 3 shows the effectiveness by the performance of objective function value. Here, all data are normalized by those of w/o SR·DC. The result of 16 nodes isn't shown in this paper because w/o SR·DC couldn't be solved. The performances of the proposed SR shows almost the same as those of w/o SR·DC. Objective function values of original and proposed SR with DC are deteriorated by 6% at most compared with those without DC. However, considering the feasibility of computation, we can conclude that the proposed SR with DC is the most effective and hopeful.

VI. CONCLUSION

In this paper, we proposed a heuristic routing design method for the multi-layer network design for reducing computation time to solve the MILP problem. The results of calculation experiments showed that the proposed SR with DC is most effective for the computation time and the performance deterioration is very little. Therefore, we conclude that the proposed SR with DC is the most effective calculation method for middle scale networks. The applicability to large scale networks with a few hundred nodes is for further study.

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