Improved Selective Randomized Load Balancing in Mesh Networks

Xiaoning Zhang, Lemin Li, Sheng Wang, and Fei Yang

ABSTRACT—We propose an improved selective randomized load balancing (ISRLB) robust scheme under the hose uncertainty model for a special double-hop routing network architecture. The ISRLB architecture maintains the resilience properties of Valiant's load balancing and reduces the network cost/propagation delay in all other robust routing schemes.

Keywords—Hose uncertainty model, Valiant's load balancing, double-hop routing network architecture.

I. Introduction

Recently, the approach of Valiant's load balancing has been implemented in backbone networks for the hose model [1]. In [2], the authors proposed Valiant's randomized load-balancing (RLB) routing scheme, which has two steps. Based on the RLB routing scheme, new double-hop architectures have been introduced, such as IP/MPLS-over-WDM networks [3] (see Fig. 1). In the double-hop network architecture shown in Fig.1, the switching circuit by optical crossconnect (OXC) for phase 1 routing is constructed in advance; for phase 2 routing, the intermediate nodes find the destination node of traffic by IP packet routers and deliver traffic to its final destination using circuits. The RLB with double-hop network architecture can support any valid traffic matrix of the hose model, but RLB brings high latency and significant time-of-flight differences since all nodes in the network act as intermediate nodes for all flows. In [3], the authors proposed a selective RLB (SRLB) scheme based on RLB. The SRLB scheme performs a two-phase routing like RLB. In SRLB, M ($M<N$) nodes with the M shortest path trees (computed among all nodes) of the network are selected as intermediate nodes. Thus, each node distributes $1/M$ of its traffic to M intermediate nodes, and the intermediate node transfers the received traffic to the final destination. The SRLB scheme inherits the properties of RLB, reducing the network cost/propagation delay.

In this letter, we propose an improved selective randomized load balancing (ISRLB) robust scheme. The ISRLB scheme can route any traffic matrix under the hose model and has a lower network cost and propagation delay.

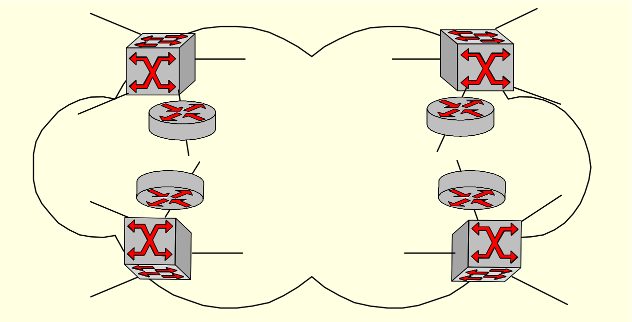

Fig. 1. Double-hop IP/MPLS-over-WDM network architecture. (square network elements: optical crossconnects; round network elements: IP packet routers).

II. Problem Definition

A physical network topology $\boldsymbol{G}(\boldsymbol{N}, \boldsymbol{E})$ consists of a weighted graph, where $\boldsymbol{N}$ is the set of network nodes and $\boldsymbol{E}$ is the set of physical unidirectional links connecting the network nodes. The node number and the unidirectional link number in the physical network are denoted by N and E, respectively. In our study, the ingress/egress capacities of the network node are

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equal. In the hose model, $\boldsymbol{T}(D_i)=[D_0, D_1,\cdots, D_{N-1}]$, D_i denotes the maximum ingress/egress capacity with i as the source/destination node ($0\leq i\leq N-1$).

Our goal is the following. Given a physical network topology and the hose uncertainty model, we propose the robust scheme to reduce the network cost/ propagation delay for the double-hop IP/MPLS-over-WDM network. The definition of IP/MPLS-over-WDM network cost is defined in [3]. The network cost includes the costs of three main functions: nodal circuit switching (*cost_circuit_switching*), nodal packet switching (*cost_packet_switching*), and the total WDM link (*cost_WDM_link*); thus,

$$\begin{aligned} network\_\cos t &= circuit\_switching\_cost \\ &\quad + packet\_switching\_cost + WDM\_link\_cost \\ &= circuit\_switching\_capacity * C_{sonet\_port} \\ &\quad + packet\_switching\_capacity * C_{IP\_port} \\ &\quad + WDM\_link\_capacity * C_{WDM/km}, \end{aligned} \tag{1}$$

where C_{sonet_port} is the cost of a SONET crossconnect port, C_{IP_port} is the cost of an IP router port, and $C_{WDM/km}$ is the cost of WDM transport per km of link distance, all for the same data rate. In [3]

$$C_{sonet\_port} : C_{IP\_port} : C_{WDM/km} = 130:370:1, \tag{2}$$

so we only need to calculate *circuit_switching_capacity*, *packet_switching_capacity*, and *WDM_link_capacity* to find the network cost from (1) and (2). For the double-hop IP/MPLS-over-WDM network architecture, the circuit switching capacity of one node is the maximum circuit capacity traversing through the node by OXC in phase 1 and phase 2 routing. The *cost_circuit_switching* is the sum of the circuit switching capacity of all nodes in the network. The packet switching capacity of one node depends on whether the node acts as the intermediate node in the two-step routing. If the node is the intermediate node, its packet switching capacity is the maximum packet capacity for local routing by the IP packet router in the intermediate node; if the node is not the intermediate node, then its packet switching capacity equals zero since only the intermediate node needs packet switching. The *cost_packet_switching* is the sum of the packet switching capacity of all nodes in the network. The WDM link capacity for one unidirectional link is the maximum WDM link capacity on the link for phase 1 and phase 2 routing, so the *cost_WDM_link* is the sum of the WDM link capacity for all of the unidirectional links. According to the above approaches, the network cost for the double-hop network can be calculated.

III. Improved Selective Randomized Load Balancing

We combine the basic ideas of both [3] and [4], and propose the ISRLB scheme as follows. First, ISRLB computes the shortest path trees for all network nodes with the Dijkstra algorithm. Thus, the shortest path $\boldsymbol{e}_{ij}$ for every node pair (i, j) ($i, j=0,1,\cdots, N-1$, $i\neq j$) with its distance c_{ij} can be calculated. In [4], the authors formulate the flow traffic for node pair (i, j) as $\alpha_j D_i + \alpha_i D_j$, and the shortest path distance for the node pair is c_{ij}. Thus, the total network flow cost in the network is calculated as

$$total\_flow\_cost = \sum_i \sum_i (D_i\alpha_j + D_i\alpha_i)c_{ij}, \tag{3}$$
$$i, j = 0,1,\cdots, N-1, \quad i\neq j,$$

which can be transformed to

$$total\_flow\_\cos t = \sum_i K_i\alpha_i, \quad i = 0,1,\cdots, N-1. \tag{4}$$

when $K_i=\sum_k (D_k c_{ki}+D_k c_{ik})$ ($k=0, 1,\cdots N-1$, $k\neq i$), which denotes the corresponding flow weight for node i. When minimizing the total network flow cost, our objective *network_cost* will also be minimized. Therefore,

$$\text{Minimize } total\_flow\_cost\text{: } \sum_i K_i\alpha_i \quad i = 0,1,\cdots, N-1 \tag{5}$$

with the constraint

$$\sum_{i=0}^{N-1} \alpha_i = 1, \qquad 0 < \alpha_i < 1. \tag{6}$$

All the nodes in the network are arranged as $\{n_1, n_2,\cdots, n_M, \cdots, n_N\}$ in the ascending order of their corresponding flow weights $\{K_1, K_2,\cdots, K_M,\cdots, K_N\}$. Using ISRLB, the M ($M<N$) nodes with the M lowest flow weights $\{n_1, n_2,\cdots, n_M\}$ are selected as the intermediate nodes. Thus, (5) can be transformed to

$$\text{Minimize: } \sum_i K_i\alpha_i \qquad i = n_1, n_2, \cdots, n_M \tag{7}$$

with a constraint transformed from (6):

$$\sum_{i=n}^{i=n_M} \alpha_i = 1, \qquad 0 < \alpha_i < 1. \tag{8}$$

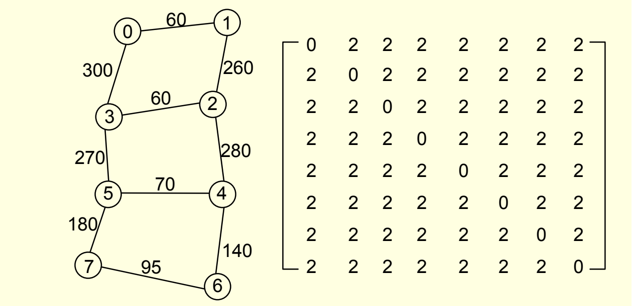
Note that in (7), when minimizing *total_flow_cost*, α_i is inverse proportional to K_i. So α_i is approximately calculated as

$$\alpha_i = (1/K_i) \Big/ \sum_i (1/K_i), \qquad i = n_1, n_2, \cdots, n_M. \tag{9}$$

Using ISRLB, M nodes $\{n_1, n_2, \cdots, n_M\}$ are selected as the intermediate nodes, and their corresponding distribution fractions are $\{\ \alpha_i$, where $i= n_1, n_2,\cdots, n_M\ \}$. By ISRLB the nonuniform traffic distribution fraction is chosen considering the network topology (shortest path tree) and hose model variation in all nodes of the network; thus, ISRLB can achieve the reduction of the network cost and propagation delay.

IV. Simulation Results and Analysis

We compare the network cost and propagation delay of our proposed ISRLB scheme with the RLB and SRLB schemes for the double-hop IP/MPLS-over-WDM network architecture by computer simulation. The simulation network topology is JANET, shown in Fig. 2(a). The number on the link denotes the distance of the link (unit: km). The hose model $\boldsymbol{T}(D_i)$ is produced in random, and D_i $(i=0, 1,\cdots,7)$ in the hose model obeys the [10, 40] uniform integer distribution. In our study, $\boldsymbol{T}(D_i)=[20, 30, 15, 18, 19, 20, 36, 40]$. An individual traffic matrix T_1 under the hose model $\boldsymbol{T}(D_i)$ is shown in Fig. 2(b).



$$\begin{bmatrix} 0 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \\ 2 & 0 & 2 & 2 & 2 & 2 & 2 & 2 \\ 2 & 2 & 0 & 2 & 2 & 2 & 2 & 2 \\ 2 & 2 & 2 & 0 & 2 & 2 & 2 & 2 \\ 2 & 2 & 2 & 2 & 0 & 2 & 2 & 2 \\ 2 & 2 & 2 & 2 & 2 & 0 & 2 & 2 \\ 2 & 2 & 2 & 2 & 2 & 2 & 0 & 2 \\ 2 & 2 & 2 & 2 & 2 & 2 & 2 & 0 \end{bmatrix}$$

Fig. 2. (a) JANET network topology and (b) an individual traffic matrix T_1.

Table 1 shows the network cost of the RLB, SRLB, and ISRLB robust routing schemes in the proposed double-hop network architecture under the hose model $\boldsymbol{T}(D_i)$ in JANET. Table 2 shows the routing average hops of the three above schemes for T_1 in JANET. In the study, the span of the adjacent nodes in the network is one hop. In Tables 1 and 2, M indicates the intermediate nodes for SRLB and ISRLB; when $M=N$, SRLB changes to RLB. The network cost shown in Table 1 is normalized by the cost of one intermediate node in SRLB and ISRLB $(M=1)$ for the current network topology.

From Table 1, we can observe that when the numbers of intermediate nodes M are identical, the cost of ISRLB is less than that of SRLB. Although the cost reduction is a small percentage, considering the results in Table 1 are normalized, the improvement of ISRLB is notable. From Table 2, we can observe that the routing average hops for T_1 of ISRLB is also less than that of SRLB. That means the propagation delay of ISRLB is also reduced. This is because SRLB selects the M intermediate nodes according to the shortest path trees and uniformly spreads the traffic among the M intermediate nodes, whereas ISRLB considers not only the shortest path trees of all the nodes, but also the hose model capacity variation in the different nodes. Thus, the M intermediate nodes in SRLB are near the geometrical center of the network; but the M intermediate nodes in ISRLB are near the center of gravity in the network. Therefore, the intermediate nodes selected by ISRLB are more reasonable than those selected by SRLB. Moreover, ISRLB non-uniformly spreads traffic among all of the intermediate nodes according to the flow weights. For these reasons, the network cost/propagation delay of ISRLB is less than that of SRLB (when $M=N$, SRLB becomes RLB).

Table 1. Network cost of RLB, SRLB, and ISRLB in JANET.

M Network cost	1	2	3	4	5	6	7	8
SRLB	1	1.02	1.04	1.05	1.08	1.10	1.12	1.15
ISRLB	1	1.01	1.02	1.03	1.06	1.07	1.09	1.13

Table 2. Routing average hops of RLB and SRLB for T1 in JANET.

M Average hops	1	2	3	4	5	6	7	8
SRLB	2.26	2.64	2.78	2.85	3.20	3.45	3.63	3.88
ISRLB	2.26	2.45	2.52	2.75	3.14	3.29	3.37	3.74

V. Conclusion

This study addressed the robust routing problem for double-hop network architecture. We proposed a new ISRLB scheme. The ISRLB scheme can support any valid traffic matrix under the hose model. Compared to the RLB and SRLB schemes, ISRLB is a significant improvement, showing lower network cost and propagation delay.

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