Load balance in hierarchical routing network
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Abstract
In this article, the problem of load balance in hierarchical routing network is studied. Since conventional shortest path first (SPF) algorithm over aggregated topology in hierarchical routing network may result in worse routing performance, a traffic sharing path selection algorithm and a variable weight scheme are put forward for hierarchical routing network, which can equilibrate the utilities of link resources and reduce the blocking probability of connections with the improvement on survivability. Simulations are conducted to evaluate proposed variable weight and traffics balance (VWTB) algorithm, which combines traffic sharing and variable weight. From the simulation results, it can be found that the proposed VWTB algorithm can balance the traffics and equilibrate the utilities of link resources significantly.

Keywords  hierarchical routing, load balance, variable weight, traffic sharing

1 Introduction
Load balance is critical in hierarchical routing network, because conventional route selection methods without load balance in hierarchical routing network may result in worse routing performance. Plentiful route selection methods for communication networks have been studied. Generally, these methods can be classified into two basic algorithms: vector-distance algorithm and link-state algorithm [1]. The convergence speed of vector-distance algorithms is very low in large-scale communication networks [2–3]. To solve this problem, link-state algorithms are proposed. However, when the communication networks continually become larger, the space of topology database will grow quadratically to the scale of the networks. The cost will be highly much if each node has to maintain such a huge database. Meanwhile, the amount of routing information exchanged in the network will increase considerably, which will reduce the routing scalability and performance correspondingly [4–5].

To deal with all these problems and reduce the space of topology database without affecting network robustness and flexibility, hierarchical routing schemes are put forward. A number of hierarchical routing algorithms have been researched and applied in asynchronous transfer mode (ATM) network. In Ref. [6], an approach to hierarchical routing is presented based on a simple algorithm that chooses a route for a connection request out of a predefined list of possible routes between a specific source-destination pair in a probabilistic way. Atlasis enhances the known leaky bucket mechanism with a learning algorithm to manage the distribution of the traffic and observe the values that the counter of the leaky bucket takes [7]. Tighter and faster control is achieved by the proposed methodology for any type of traffic source, resulting in larger statistical gain and better guarantee of the quality of service (QoS) constraints. In Ref. [8], an end-to-end routing protocol is presented, which combines the characteristics of both hierarchical and distributed routing protocols.

The methods mentioned above are all designed to select the optimal path in a hierarchical routing network with different performance measurement. And they are all based on the principle of the SPF algorithm [9–10]. In a hierarchical network, topology aggregation is obligatory and routing information loss caused by aggregation process is unavoidable. Hence paths calculated by these methods may be just approximately optimal. In a hierarchical routing network,
since the SPF algorithm may cause traffic jam on special link resources that are considered to be along the shortest path, if the shortest path calculated based on aggregated topology is not the optimal path in fact, the excessive usage of resources along this path will cause a worse routing performance in the network.

In this article, load balance is introduced and studied in hierarchical routing network to address the problems discussed above. A novel variable weight load balance routing algorithm VWTB is proposed to calculate the path in a hierarchical routing network. The remainder of this article is organized as follows. First, the routing model in a hierarchical network is depicted. Then the detailed algorithm description and theoretical analysis are given in Sects. 2 and 3. In Sect. 5, the performance of suggested schemes is simulated and evaluated. Finally, concluding remarks are presented.

2 Routing model in hierarchical network

The basic mechanism for hierarchical routing selection is demonstrated in Fig. 1. With topology aggregation and topology synchronization process, each node will have a detailed topology view for its own routing domain and aggregated topology views for the other domains.

In a hierarchical routing network, load balance can be used to optimize use of resource and routing performance. Many load balance algorithms have been studied to distribute the traffics in a network more equally by improving the path calculation algorithm [11]. Four basic methods are listed as follows.

Variable weight method: a way of calculating link weight based on the target of optimization. Select a weighted path with the SPF algorithm. The typical scheme is to dynamically configure the link weight based on the amount of available resource in the physical link. The principle is to increase the weight when the amount of available resource goes down. As a result, those links whose resources have been almost used up can be avoided when selecting path with the SPF algorithm. To equilibrate the utilities of link resources, plentiful methods can be used to calculate the weight.

Traffic sharing between multiple service paths: in this method, traffics are distributed into multiple service paths to reduce the load of single work path. This scheme is suitable for packet switched network where traffic sharing is feasible [12].

Selection from multiple paths: to reduce the complexity of algorithms that aim at multiple optimized objects, several paths are calculated first for a certain service level. Then one from these paths is select based on special policy. Thus the traffics distribution of the whole network can be more uniform [13].

Rerouting method: change the distribution of traffics by rerouting the service path. This method may cause the interruption of service. Hence, it is suitable for static network [14].

3 Routing with load balance: traffic sharing and variable weight

As discussed above, there are many ways to balance the traffics in a network. In this article, traffic sharing between multiple service paths is considered to be adopted in a hierarchical routing network. Connections with the same attributions will be assigned into several different service paths so that the network resources can be utilized more efficiently. The variable weight is also used to adjust the traffic distribution. Traffic sharing and variable weight are different methods of meeting requirement of load balance. These methods can not only settle the problems of unreasonable use of resource caused by topology aggregation and the SPF algorithm, but also reduce the blocking probability and enhance the survivability of networks. Based on this principle, a novel routing selection algorithm VWTB is proposed in this section, which is proved to yield good routing performance.

For a TE-link with initial weight value \( W_{ini} \) and total resource number \( R_{tot} \), the current weight of this TE-link is identified as \( W_{cur} \) and the amount of occupied resources in this TE-link is \( R_{occ} \).

**Definition 1** The ratio between available resource number \((R_{tot} - R_{occ})\) and the total resource number of the TE-link is defined as vacancy probability of the TE-link, which is represented by \( A_{Vac} \), i.e.

\[
A_{Vac} = \frac{R_{tot} - R_{occ}}{R_{tot}} \quad (1)
\]

When the value of \( A_{Vac} \) is big, little resources are used in this TE-link and the current weight value \( W_{cur} \) of this TE-link should be reduced to improve the utilization probability. Conversely, when the value of \( A_{Vac} \) is small, \( W_{cur} \) should be increased to avoid traffic jam on this link. Thus \( W_{cur} \) should be in inverse proportion to \( A_{Vac} \). In VWTB, the formula of weight adjustment is as follows.

\[
W_{cur} = \frac{1}{C_{con} + A_{Vac}} W_{ini} \quad (2)
\]

In this formula, \( C_{con} \) is a constant parameter, the range of \( A_{Vac} \) is \([0, 1]\), and thus the range of \( W_{cur} \) is...
\[ W_{\text{ini}} / (C_{\text{con}} + 1), W_{\text{ini}} / C_{\text{con}} \]. It is obvious that the value of \( W_{\text{con}} \) can change in a large scope when \( C_{\text{con}} \) is small. Thus \( C_{\text{con}} \) is also called adjustment factor. The range of \( W_{\text{con}} \) can be adjusted by configuring different values of \( C_{\text{con}} \). Generally, the variable weight policy is used to enlarge the range of \( W_{\text{con}} \) and increase the value of \( W_{\text{con}} \) when resources are almost exhausted. Hence a small value of \( C_{\text{con}} \) is more condign. In VWTB, let \( C_{\text{con}} = \frac{1}{(R_{\text{ini}} W_{\text{ini}})} \). Since the value of \( R_{\text{ini}} \) or \( W_{\text{ini}} \) is usually very large in physical link, the range of \( W_{\text{con}} \) can be guaranteed to change in a large scope.

For the routing selection based upon aggregated topology by source node, the policy of traffic sharing is used to compensate for the inaccuracy in routing calculation caused by the loss of topology information. The principle of traffic sharing to satisfy load balance is depicted as follows. Connections that have the same attributions such as the same source node and destination node or the same class of service, can be aggregated into a single traffic group, whereas, the granularities of these connections may not be the same one. When calculating work paths, these connections will not be assigned to a single work path even if there was fitful path. Instead, these connections will be distributed into multiple work paths based upon a special policy. These work paths are called sharing paths for the traffic group. There are two basic separating methods for these sharing paths: link disjoint and node disjoint.

If traffic sharing is adopted and the number of traffic sharing path is 2, the source node 1.1 will calculate a sharing path \( P_1 \) based on the aggregated topology, i.e. \( 1.1 \rightarrow 1.2 \rightarrow 1.3 \rightarrow 2.2 \rightarrow 2.3 \rightarrow 3.2 \rightarrow 3.3 \). The corresponding physical path is \( 1.1 \rightarrow 1.2 \rightarrow 1.3 \rightarrow 2.2 \rightarrow 2.3 \rightarrow 3.2 \rightarrow 3.3 \). Then a sharing path \( P_2 \) is also calculated based on the aggregated topology, i.e. \( 1.1 \rightarrow 1.6 \rightarrow 1.5 \rightarrow 2.1 \rightarrow 2.5 \rightarrow 3.1 \rightarrow 3.3 \). The corresponding physical path is \( 1.1 \rightarrow 1.6 \rightarrow 1.5 \rightarrow 2.1 \rightarrow 2.6 \rightarrow 2.5 \rightarrow 3.1 \rightarrow 3.4 \rightarrow 3.3 \). The other component connections will be loaded into \( P_1 \) and \( P_2 \), respectively. Generally, the range of traffic sharing path number is within \([1,3]\). To restrict the amount of sharing path, the number of VCs for a connection should be restricted to no more than the sharing path. The algorithm of traffic sharing is described below.

**Step 1** On receiving the connection request, the source node will check the VC number and traffic sharing number of the traffic group to which the connection belongs.

**Step 2** If current VC number is smaller than the traffic sharing number, new VC will be calculated by the source node based on the aggregated topology. The new VC should comply with the disjoint rules with the other sharing paths for the same traffic group. A variable defined as Index is used to point to the current VC. Go to Step 4.

**Step 3** If current VC number is equal to traffic sharing number, look up the value of Index and move to the next VC available. This VC is considered as current VC. Go to Step 6.

**Step 4** If the current VC meets the requirement of connection, go to Step 6.

**Step 5** Otherwise go to Step 2 and keep searching available VC. If current VC number is equal to traffic sharing number and none of the VC meets the requirement, the connection will be rejected.

**Step 6** Path setup process will be initiated by the source node along the loose explicit route calculated on the aggregated topology.

### 4 Simulations and performance evaluation

#### 4.1 Simulation environment

To analyze and evaluate the performance of VWTB, a simulated hierarchical routing network with four routing areas is
constructed. Each area consists of 20 routing nodes, of which four are border ones. The topologies of these areas are generated randomly and the node degree is randomly chosen from a uniform distribution over the interval [2,4]. Each area has connections to all the other areas so that a full-mesh inter-area topology is constructed. The original weight value of each link in the network is 10. The total bandwidth of intra-area link is synchronous transfer module (STM)-16 and that of inter-area link is STM-64. Connection with bandwidth requirements STM-1 are distributed randomly between each border node pair.

To analyze the performance of VWTB algorithm in different network traffic environment, 30 connections, 60 connections, 120 connections and 180 connections are loaded into the network to simulate the light load distribution, proper load distribution, heavy load distribution and over loading distribution environment, respectively.

**Definition 2** When a certain traffic distribution is loaded into a network, physical link that provides bandwidth resources to the traffics is defined as effective link to this traffics distribution. Otherwise the link is defined as no effective link.

When traffics are loaded onto the network, to evaluate the effect of routing algorithms on traffic distribution, two measures are introduced: effective load distribution (ELD) and total load distribution (TLD). Total number of resource consumption here means the total amount of the consumed bandwidths in the network. ELD is the ratio of total number of resource consumption to the total number of effective links. TLD is the ratio of total number of resource consumption to the total number of links. ELD and TLD both indicate the distribution of network load.

### 4.2 Performance evaluation of traffic sharing algorithm

The performance of traffic sharing algorithms is analyzed in this section. In the simulations routing algorithm without traffic sharing, routing algorithm with traffic sharing number 2, routing algorithm with traffic sharing number 3 are adopted respectively under four traffic distribution schemes i.e. light load distribution, proper load distribution, heavy load distribution and over loading distribution.

For convenience routing algorithm without traffic sharing is depicted as scheme A, routing algorithm with traffic sharing number 2 is depicted as scheme B and routing algorithm with traffic sharing number 3 is depicted as scheme C. Fig. 2 shows the curves of ELD and TLD for scheme A, B and C.

It can be seen from Fig. 2(a) that the value of ELD reduces with the adoption of traffic sharing because more physical links are used and the traffic distribution of the whole network is more uniform. However, the ELD of scheme B is higher than that of scheme A when the number of connections is 120. The reason is that under heavy load distribution scheme A begins to cause blocking probability of the connections while scheme B can guarantee the successful setup for all the connections due to the adoption of traffic sharing algorithm.

Since the network will carry more traffic under scheme B than scheme A, the corresponding ELD of scheme B has to go up. From the figures, when the network is under over loading traffic distribution, all of these schemes will cause blocking probability of the connections, as a result, the ELD of scheme B and C is smaller than that of scheme A.

Fig. 2(b) shows the curve of TLD of the network. Since several sub-shortest paths are used in traffic sharing algorithm to undertake the load of traffic group, the amount of consumed resources in the whole network will be more than that of routing algorithm without traffic sharing. It can be seen in Fig. 2(b) that the TLD of schemes B and C are always larger than that of scheme A. Traffic sharing is a trade-off policy that equilibrates the utilization of link resources at the
cost of more resources consumption. The amount of resource consumption will grow even larger with the increasing number of traffic sharing paths. From Fig. 2(b) the TLD of scheme C is larger than that of scheme B. However, under heavy load distribution and over loading distribution, the TLD of scheme C is smaller than that of scheme B. The blocking probability of scheme B is much lower than that of scheme C and the network with scheme B will undertake more traffics. As a result, the TLD of scheme B is higher.

When heavy load distribution and over loading distribution are loaded onto the network, several connections are rejected due to lack of resource. Fig. 3 shows the blocking probability caused by three schemes under heavy load distribution and over loading distribution. The blocking probability of scheme B is always the lowest while that of scheme C is the highest. Since more traffic sharing paths are adopted in scheme C, the excessive utilization of sub-shortest paths causes exhaustion of network resource. Overall, proper utilization of traffic sharing algorithm can equilibrate the traffic distribution and enhance the throughout of network. However, it is a trade-off policy at the cost of more resource consumption. Hence, the number of traffic sharing paths should not be overfull. In the ensuing sections, the number of traffic sharing path is set to 2.

In the variable weight method, every TE-link in the network is set to a variable weight. The weight is changed and broadcasted when the bandwidth occupation of the TE-link is changed. Hence every node has a whole view of the network TE-link weight which is stored in its local database. The source node of a connection can choose the best path based on the weight from different sharing paths.

Fig. 4 gives the curves of ELD and TLD caused by four schemes. It can be seen from Fig. 4(a) that the value of ELD reduces with the adoption of variable weight. Scheme D that combines the variable weight with traffic sharing yields the lowest ELD distribution. As a result, the resources of the whole network are assigned more uniformly. Under over loading distribution scheme D can guarantee the lowest blocking probability of the connections and more traffics can be carried over the network. It is the reason why scheme D has the highest ELD under over loading traffic. However, the TLD of schemes with variable weight are higher than that of without variable weight. Variable weight is also a trade-off policy that equilibrates the utilization of link resources at the cost of more resources consumption.

### Table 1 Routing schemes in simulation

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Traffic sharing</th>
<th>Variable weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme A</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Scheme B</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Scheme C</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Scheme D (VWTB)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4.3 Routing performance of VWTB algorithm

In this section the routing performance of the proposed VWTB algorithm is analyzed in the simulation. The routing performance of four kinds of schemes described in Table 1 is compared.
Fig. 5 shows the blocking probability of four schemes under heavy load and over loading distributions. Scheme D can always keep the lowest blocking probability, which proves the better throughout performance yielded by scheme D.

5 Conclusions

In this article, the performance of load balance in hierarchical routing network is investigated. Since the adoption of topology aggregation and the SPF algorithm may cause traffic jam in certain physical links and result in worse routing performance in the network, traffic sharing and variable weight are introduced in the hierarchical routing network to address these problems.

From the simulation results, it can be concluded that the proposed VWTB algorithm can balance the traffics and equilibrate the utilization of link resources significantly. Meanwhile, the blocking probability of VWTB is lower than the conventional SPF algorithm. Since traffic sharing is a trade-off policy that equilibrates the utilization of link resources at the cost of more resources consumption, the consumption of resources will grow even larger with the increasing number of traffic sharing paths. Hence the number of traffic sharing paths should not be overfull and the suggested number is 2.

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References


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