A scalable topology aggregation algorithm for QoS routing in hierarchical networks

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Abstract: Topology aggregation is necessary for scalable QoS routing mechanisms. The key issue is how to gain good performance while summarizing the topological information. In this paper, we propose a new method to describe the logical link, which is simple and effective in network with additive and constrained concave parameters. We extend the method to network associated with multi-parameters. Furthermore, we propose a modified star aggregation algorithm. Simulations are used to evaluate the performance. The results show that our algorithm is relatively good.

Key words: QoS-based routing; topology aggregation; multiple parameters; scalable

Now that the world faces a great need for providing new network services such as VoIP and interactive multimedia, etc., the importance of QoS routing has attracted much more attention. QoS routing can identify a feasible route that satisfies multiple constraints (performance metrics, e.g., bandwidth, delay, jitter, and loss probability, which are required by all QoS-oriented services). QoS routing consists of two basic tasks: gathering and distributing the link information of the network; searching this information for a feasible path with QoS constraints. However, it requires an enormous amount of bandwidth, time and space to distribute network topology and star information. In order to reduce the complexity of QoS routing computing, a good star aggregation algorithm is needed. Scalability is the main issue. PNNI[1] standard proposed a topology aggregation protocol, in which a scalable hierarchical framework is defined. Nodes are grouped into clusters called peer groups (PGs, the lower layer of the logic network). Although PNNI defines the framework, it does not give algorithms to do the aggregation. Topology aggregation is very difficult, especially when it needs to consider multiple metrics (bandwidth, delay, loss probability, etc.)[2,3].

In traditional approaches, topology aggregation is performed in two steps. First, b border nodes of a PG are taken out to construct a fully connected mesh, with a direct link between each pair of border nodes. The inside nodes excluding border nodes of the original PG are simplified. The total space needed for the mesh is $O(b^2)$, which is still too expensive. Second, aggregate the full mesh to a more compact topology. In both steps, information loss cannot be avoided. Ref. [4] compared three traditional topology aggregation schemes; the performance difference wasn't large.

Some algorithms are proposed to solve topology aggregation problems with multiple parameters. In Ref. [5], the author suggests an extra factor besides the parameters to describe each logical link. This factor comes from the "best" path between two border nodes. This approach may introduce big errors because the information of the other paths is discarded. Ref. [6] proposed a linear segment approach, which used a line to approximate all the actual paths between two borders. This approach has low loss though it is hard to extend to more than two parameters. The full mesh network can be an aggregate to a star network, with the space complexity of $O(b)$. But a simple star network may be far away from the original network. In Ref. [2], the full mesh is compacted to a spanning tree. Ref. [5] proposed a source-oriented approach, where the full mesh network does not need to be compacted. But the topologies distributed from the PG borders are not the same. Confusion is easy to bring and the complexity of the whole is not reduced. Ref. [7] proposed a partial optimization method which can be used together with other algorithms.

In this paper, we propose novel algorithms for topology aggregation with additive and concave parameters. Using these methods, we can conveniently describe links with multiple parameters. Simulation results show that our algorithm performs well.

The remainder of this paper is organized as follows. In section 1, we describe topology aggregation. Sections 2 and 3 describe the aggregation

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algorithm. The performance evaluation is given in section 4. Section 5 concludes this paper.

1 Topology Aggregation

Definition 1 Topology aggregation problem. Consider a PG = (V, B, E), where V is the set of nodes, $B \subset V$ is the set of border nodes, and E is the set of directed links among the nodes in V. Given two border nodes s and t, there are multiple physical paths that can connect them. Let P be the set of n paths,

$$P = \{p_1(m_1^1, \cdots, m_1^k), \cdots, p_n(m_n^1, \cdots, m_n^k)\}$$

Each path p_i is associated with k QoS metrics, $m^1, \cdots, m^k$. A topology aggregation algorithm must find a logic link $l = (m^1, \cdots, m^k)$ to describe all these paths. When the number of metrics grows, it is more and more difficult to find the "best" logic link, or even a "better" one. Fig.1 is an example of a PG, which has 4 border nodes, represented by black points.

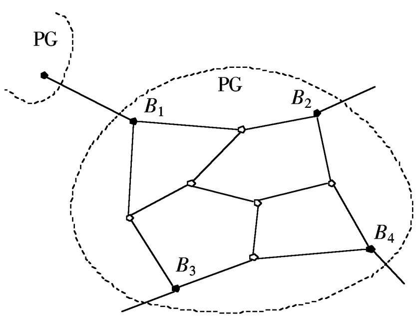

Fig.1 PG and border nodes

There are four distinct paths from B_1 to B_2. We represent these four paths by a single logical link with appropriate metric values. First we aggregate an actual PG to a full-mesh network, where only the border nodes are included. It is still too expensive to distribute the state information of a full-mesh network in network. In section 2, we compact it into a simpler network with link complexity of $O(b)$.

2 Full-Mesh Topology Aggregation

Next we show how to aggregate the PG to a full-mesh network. Fig.2 shows how to aggregate the paths between nodes. For example, each physical link is associated with QoS parameters pair (delay, bandwidth). In Fig.2, the shaded area represents the actual admissible region. A connection request whose QoS requirement (D_{req}, B_{req}) falls in this region will be accepted. Otherwise, the request will be rejected because there is no physical path that meets its QoS requirements. In an aggregated full-mesh network, the physical paths will be represented by a single logical link. How to represent this new logical link with QoS parameters is the key issue. In this paper, we present a new method.

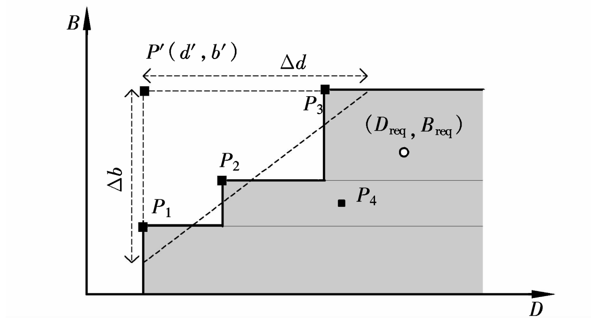

Fig.2 Admissible region between border nodes B_1 and B_2

We use a modified parameter pairs $[(d', b'), (\Delta d, \Delta b)]$ to describe a logical link. Pair (d', b') is the best-case point P' in Fig.2, $(\Delta d, \Delta b)$ describes the distance between P' and a modified line, which is illustrated in dotted line in Fig.2. How to choose the line determines the accuracy of this method. Ref.[6] proposed a linear segment method, the line can be found using the least square algorithm. There are other methods to find this line.

Next we give a definition, which describes the link associated with multiple parameters. Then we give the accepted conditions of the connection request that should be satisfied.

Definition 2 Modified logical link. A logical link between border nodes B_1 and B_2 is associated with the parameters:

$$[(m^1, \cdots, m^i, m^{i+1}, \cdots, m^k),$$
$$(\Delta m^1, \cdots, \Delta m^i, \Delta m^{i+1}, \cdots, \Delta m^k)]$$

where $m^1, \cdots, m^i$ are additive metrics, examples are delay, jitter, cost and hop-count; $m^{i+1}, \cdots, m^k$ are concave metrics, an example is bandwidth. Here we don't consider multiplicative metrics, an example is reliability; it is easy to change them into additive metrics. $\Delta m^1, \cdots, \Delta m^i$ are modifications to additive metrics, $\Delta m^{i+1}, \cdots, \Delta m^k$ are modifications to concave metrics.

Theorem Considering a connection request with QoS requirement $(Q^1, \cdots, Q^i, Q^{i+1}, \cdots, Q^k)$, it can be accepted by actual network when the following conditions are all satisfied:

$$Q^j \geqslant m^j \qquad 1 \leqslant j \leqslant i \tag{1}$$

$$Q^j \leqslant m^j \qquad i+1 \leqslant j \leqslant k \tag{2}$$

$$\sum_{j=1}^{k} \left| \frac{Q^j - m^j}{\Delta m^j} \right| \geqslant 1 \tag{3}$$

For example, given a network in which links are associated with bandwidth and delay, as illustrated in Fig.2, and a connection request is (D_{req}, B_{req}). Then condition (3) is

$$\left|\frac{D_{\text{req}} - d'}{\Delta d}\right| + \left|\frac{B_{\text{req}} - b'}{\Delta b}\right| \geqslant 1$$

It describes the shaded area in Fig.2. These three conditions will be used in section 3.

Proof In the theorem, (1) defines the condition of additive parameters, (2) defines the condition of concave parameters, (3) defines the relationship of all parameters. Consider a (Delay, Bandwidth) request. In Fig.3, a connection request accepted by the actual network should fall in the shaded area. Request (D_1, B_1) can be accepted, request (D_2, B_2) and (D_3, B_3) cannot be accepted. (D_3, B_3) is out of the shaded area, because it cannot satisfy condition (2). (D_2, B_2) cannot satisfy condition (3). Actually, line xy can be described as

$$\left|\frac{D_{\text{req}} - d'}{\Delta d}\right| + \left|\frac{B_{\text{req}} - b'}{\Delta b}\right| = 1$$

With three or more parameters, the theorem is always correct.

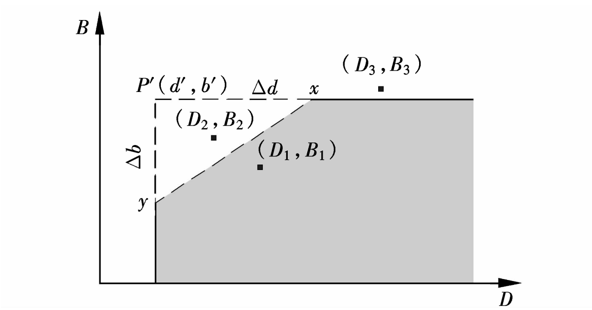

Fig.3 Accepted area of connection requests

When used in actual routing computing, not every Δm is needed. For example, if the delay is not very important in QoS requirement, the link can be described as

[(bandwidth, delay), (Δbandwidth)]

The computing can be simplified.

3 Topology Aggregation Algorithm

The method in section 2 aggregates the network into a full-mesh network. The space complexity of a full-mesh network is $O(b^2)$. It should be changed to a more compact topology. One of the representative topologies in PNNI is star. Star cannot be used directly in topology aggregation[2]. In this paper we propose a modified star approach. In Fig.4, nucleus n is a virtual node, and all border nodes connect via virtual links to n. The dotted curves show the modification to star topology.

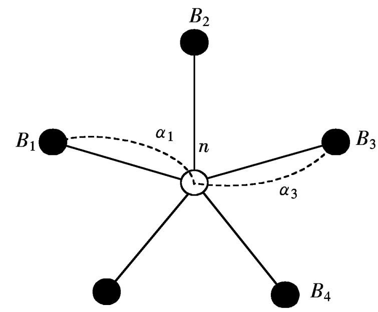

Fig.4 Modified-star topology

Let l^{m}_{ij} be the virtual link connecting node i and j, m means mesh. For example, parameter $l^{\text{m}}_{ij}.d$ is an additive metric, $l^{\text{m}}_{ij}.b$ is a concave metric. Let l^{s}_{in} be the spoke connecting border node i and nucleus n, s means star. For example, parameter $l^{\text{s}}_{in}.d$ is an additive metric, $l^{\text{s}}_{in}.b$ is a concave metric. Let B be the set of border nodes, and L, the set of all links in full-mesh topology.

Actual network topology is asymmetric. A star is always asymmetrical. To make the star more flexible, PNNI suggests inter-border links called bypasses. But bypasses are not very easy to choose. In this paper, we use modification parameter α to describe the asymmetry.

We now give the process of finding the spokes and the modifications.

① Find $l^{\text{s}}_{in}.d$. Choose any two nodes i and j in B, let $l^{\text{s}}_{in}.d = \frac{1}{2}\min_{i,j\in B}\{l^{\text{m}}_{ij}.d\}$. Remove i from B, remove link l^{m}_{ij} from L.

② Find $l^{\text{s}}_{in}.b$. Let $l^{\text{s}}_{in}.d = \max_{j\in B}\{l^{\text{m}}_{ij}.b\}$, where i is the one in ①.

③ Repeat ① and ② until B is null.

④ If L is not null, let the remaining links be L'. Additive and multiplicative α of any node k are

$$\alpha^{\text{s}}_{kn}.d = E_{kj\in L'} l^{\text{m}}_{kj}.d - l^{\text{s}}_{kn}.d$$

$$\alpha^{\text{s}}_{kn}.b = \min_{kj\in L'}\{l^{\text{m}}_{kj}.b\}$$

To those nodes that are not in L', set the additive modifications of them to 0, and concave modifications to ∞.

①, ② and ③ assign the better values to border nodes. ④ gives the modification parameters α. As shown in ④, α is computed from the remaining set L' of full-mesh L. If the network is symmetric, L' will be null, and α will have "good" values. That is, α can describe the symmetric attributes of the network.

At last, in the modified star topology, the link which connects border node i and nucleus n is associated with $[(l^{\text{s}}_{in}.d, l^{\text{s}}_{in}.b)$, $(\alpha^{\text{s}}_{in}.d, \alpha^{\text{s}}_{in}.b)$, $(\Delta l^{\text{s}}_{in}.d, \Delta l^{\text{s}}_{in}.b)]$. When computing a QoS path, the additive and concave metrics of the virtual link between border node i and j are

$$l_{ij}^{s}.d = l_{in}^{s}.d + l_{jn}^{s}.d + \alpha_{in}^{s}.d + \alpha_{jn}^{s}.d$$

$$l_{ij}^{s}.b = \min\{l_{in}^{s}.b, l_{jn}^{s}.b, \alpha_{in}^{s}.b, \alpha_{jn}^{s}.b\}$$

According to condition (1), (2) and (3), a QoS request $(Q.d, Q.b)$ can be accepted if

$$Q.d \geqslant l_{ij}^{s}.d$$

$$Q.b \leqslant l_{ij}^{s}.b$$

$$\left|\frac{Q.d - l_{ij}^{s}.d}{\Delta l_{ij}^{s}.d}\right| + \left|\frac{Q.b - l_{ij}^{s}.b}{\Delta l_{ij}^{s}.b}\right| \geqslant 1$$

When the number of parameters is greater than two, it is difficult to aggregate practicable topology in most QoS routing network[5]. Considering the important parameters firstly is a tradeoff in large topology aggregation. For example, a network is constrained by 3 parameters, d_1 and d_2 are additive metric, b is concave metric. d_1 is the most important parameter.

Step ① is modified as

① Find $l_{in}^{s}.d_1$ and $l_{in}^{s}.d_2$. Choose any two nodes i and j in B, let $l_{in}^{s}.d_1 = \frac{1}{2}\min_{i,j\in B}\{l_{ij}^{m}.d_1\}$. Remove i from B, remove link l_{ij}^{m} from L. Let $l_{in}^{s}.d_2 = \frac{1}{2}l_{ij}^{m}.d_2\}$, where i, j are chosen by d_1.

Step ④ is modified as

$$\alpha_{kn}^{s}.d_1 = E_{kj\in L'}l_{kj}^{m}.d_1 - l_{kn}^{s}.d_1$$

$$\alpha_{kn}^{s}.d_2 = E_{kj\in L'}l_{kj}^{m}.d_2 - l_{kn}^{s}.d_2$$

The running time complexity of ①,② and ③ is $O(b^2)$, that of ④ is $O(b^2)$. The total complexity of this algorithm is $O(b^2)$.

4 Performance Evaluation

We use the success ratio of feasible connection requests to evaluate topology aggregation methods. A connection request is feasible if it is admissible based on the actual state of the network. Using the aggregated information, the source node may or may not find a route for a feasible request.

$$\text{Success ratio} = \frac{\text{total number of realized requests}}{\text{total number of feasible requests}}$$

We compare our algorithm (MSA) with LSRA[6]. We choose the way described in Ref. [6] to generate random network topology. The network topology consists of 12 domains, each has 20 to 40 nodes. All nodes are connected by directed links. Each link is associated with delay and bandwidth. The delay over each link is randomly chosen from a uniform distribution over [4 ms, 40 ms], and the bandwidth is chosen from [0.2 Mbit/s, 10 Mbit/s]. The delay requirement of a connection is distributed over [50 ms, 150 ms], and the bandwidth requirement is distributed over [0.1 Mbit/s, 10 Mbit/s]. The experiment is repeated 20 times. Fig.5 shows the success ratios of the two algorithms. Our MSA achieves good performance.

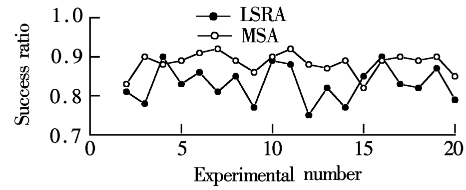

Fig.5 Performance of two approaches with (delay, bandwidth) constrained

5 Conclusion

In this paper, we propose two modified methods for topology aggregation in multiple constrained networks. The contributions of this paper are twofold. First, in full-mesh topology aggregation, we introduce a scalable approach to describe multiple constrained networks. Second, in a modified-star topology aggregation, we propose an algorithm considering the "good" and "bad" link parameters. Extensive simulations show that our algorithm achieves a good success ratio.

References

[1] The ATM Forum. Private network-to-network interface specification version 1.0 [S]. 1996.

[2] Lee W C. Spanning tree method for link state aggregation in large communication networks [A]. In: *IEEE Proceedings of the INFOCOM'95* [C]. 1995. 297-302.

[3] Awerbuch B, Shavitt Y. Topology aggregation for directed graphs [A]. In: *Proceedings of ISCC'98* [C]. 1998.

[4] Chung Kyung Taek, Kim Byun Gon, Kim Kwan Woong. Performance evaluation of topology aggregation in PNNI network [A]. In: *Electrical and Electronic Technology*, *Proceedings of IEEE Region* 10 *International Conference* [C]. 2001, **1**: 157-160.

[5] Korkmaz T, Krunz M. Source-oriented topology aggregation with multiple QoS parameters in hierarchical ATM networks [A]. In: *IEEE IWQoS* [C]. 1999. 137-146.

[6] Lui King-shan, Nahrstedt Klara. Topology aggregation and routing in bandwidth-delay sensitive networks [A]. In: *IEEE GLOBECOM'00* [C]. 2000, **1**: 410-414.

[7] Pak Wooguil, Bahk Saewoong. Partial optimization method of topology aggregation for hierarchical QoS routing [A]. In: *IEEE ICC* [C]. 2002, **2**: 1123-1127.

应用于分级网络的可扩展拓扑聚集算法

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摘　要　拓扑聚集在可扩展的路由机制中十分重要,如何在简化网络拓扑信息的同时获得好的性能,是拓扑聚集算法的关键问题.本文提出了一个描述逻辑链路的新方法,能够简单有效地描述加性和乘性参数约束的网络,并扩展到多参数约束的情况.在此基础上,提出了一个改进的星型聚集算法.仿真结果表明该算法具有很好的性能.

关键词　QoS 路由；拓扑聚集；多参数；可扩展

中图分类号　TP393