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Aggregation of traffic information for hierarchical routing reconfiguration ☆

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ABSTRACT

One approach to accommodate a large and time-varying traffic is dynamical routing reconfiguration based on the traffic matrix (TM), which is obtained by monitoring the amounts of traffic between all node pairs. However, it is difficult to monitor and collect the amounts of traffic between all node pairs in a large network. Though reconfiguration methods only based on the amount of traffic on each link have been proposed to overcome this problem, these methods, require a large calculation time and cannot be applied to large networks. This paper discusses a dynamic routing reconfiguration method that can adapt routes to changes in traffic within a short period only based on the amount of traffic on each link. We introduce a hierarchical routing reconfiguration based on the monitored amount of traffic on each link to reduce the calculation time. Moreover, we also propose a method of aggregating traffic information that is suitable for hierarchical routing reconfiguration based on the monitored amount of traffic on each link. Our method aggregates traffic information so that the upper bounds of link utilization after route changes can be calculated by using the aggregated traffic information. Thus, the routing controller using the aggregated traffic information calculates the suitable routes without large link utilization by taking into consideration the upper bounds of the link utilization. This paper evaluates our method through simulations, where we demonstrated that the routing reconfiguration of each layer calculated suitable routes with short calculation times. Then, we reduced the link utilization immediately after traffic had changed by combining the routing reconfiguration of each layer.

1. Introduction

Various new applications such as cloud storage services have been deployed over the Internet. Such applications increase the amount of traffic and cause unpredictable changes in traffic. A network must accommodate such time-varying traffic efficiently. However, if routing optimal to a current traffic is configured, the routing configuration becomes no longer suitable after traffic changes.

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One approach to accommodate such a large and time-varying traffic is dynamical routing reconfiguration [1–12]. In these methods, a central server dynamically calculates the routes periodically based on the traffic matrix (TM), which is obtained by monitoring the amounts of traffic between all node pairs. Then, the nodes within a network are configured based on the calculated routes. In this paper, we call the central server *routing controller*. However, it is difficult to monitor and collect the amounts of traffic between all node pairs in large networks, because the amount of traffic required to be monitored is $O(N^2)$ where N is the number of nodes. Thus, the routing reconfiguration method using the monitored TM is hard to control the routes in real time to follow changes in traffic that occur in short periods.

Routing reconfiguration methods only based on the amount of traffic on each link have been proposed to overcome this problem [7,8]. The amount of traffic on each link can easily be monitored and collected, because the amount of traffic required to be monitored is $O(L)$ where L is the number of links. The amount of traffic on each link in these methods is used as the constraint on the TM. They then calculate the routes to avoid large utilization of links for all TMs that satisfy the constraints. These methods, however, cannot be applied to large networks, because the calculation time to obtain the largest link utilization for all TMs satisfying the constraints is $O(N^8L^2)$, because the L linear programmings which have N^2 variables and L constraints are required to be solved, and the linear programming with n variables and l constraints can be solved at $O(n^4l)$ by using the method by Renegar [13].

One approach to reducing the calculation time is to hierarchically divide the network into areas; the area with the lowest layer is constructed from a small number of nodes, and the area with the upper layer is constructed from multiple areas of the lower layer. The multiple layers are constructed by continuing to construct the area of the upper layer from multiple areas of the lower layer. The traffic information for each area is aggregated and exchanged between the layers. Then, the routing controller of each area of each layer calculates the routes by only using aggregated traffic information. The time to calculate the routes is significantly reduced by hierarchically dividing the network and aggregating traffic information. We will call this method *hierarchical routing reconfiguration* after this.

The routing controller of each layer is required to predict link utilization after the route has changed only from aggregated traffic information to effectively carry out the hierarchical routing reconfiguration. If we use aggregated traffic information that only includes the amount of traffic in each area and the degree of congestion, we cannot accurately predict link utilization after the route has changed. This is because we cannot obtain the amount of traffic in flows whose routes can be changed from the traffic information aggregated at the lower layer. As a result, the routing reconfiguration using aggregated traffic information may even increase link utilization. For example, the link between E–F is a bottleneck link, and all flows between A–B, A–D, C–B, and C–D pass the link between E–F in Fig. 1. However, we cannot know that the traffic between A–B, A–D, C–B, and C–E are concentrated on link E–F from the aggregated traffic information without knowledge of the detailed information of the topology within the area. As a result, the routing controller using aggregated traffic information may increase the traffic for all these flows, and cause large utilization of link E–F.

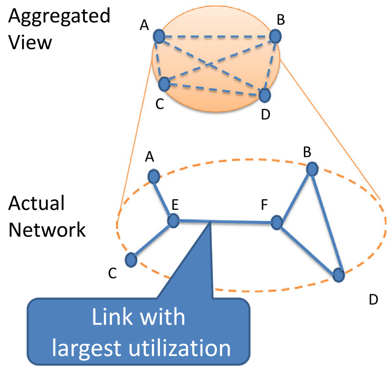

Fig. 1. Example of simple aggregation of traffic information.

This paper discusses the traffic information aggregation method for the hierarchical routing reconfiguration, and the routing reconfiguration method using the aggregated traffic information. As describe above, one of the most important issues in this approach is to calculate routes that can effectively reduce link utilization only from aggregated traffic information. In our traffic information aggregation method, the aggregated traffic information is generated so as to include the information of the links whose utilization may become large and the constraints on TMs. The upper bound of the link utilization after the route change is calculated by using the constraints on TMs obtained from the aggregated traffic information. Thus, we reconfigure the routes based on the aggregated traffic information to reduce the link utilization by taking into consideration the upper bounds of the link utilization.

The routing controller of the lower layer in the hierarchical routing reconfiguration uses detailed traffic information on narrower areas to change routes locally to mitigate large utilization of links. The routing controller of the upper layer uses aggregated traffic information on wider areas to mitigate large utilization of links that cannot be mitigated by changes in local routes.

The traffic information used by the routing controller of each area at each layer in the hierarchical routing reconfiguration only includes a small number of links. Thus, the calculation time for routing reconfiguration method that takes into consideration all TMs under the constraints defined by aggregated traffic information is short. The number of nodes handled by the routing controller of each area and the number of links included in aggregated traffic information are reduced by hierarchically dividing the network and using aggregated traffic information. The calculation time to obtain the largest link utilization for all TMs required by the routing controller of each area is $O(N^8L^2/R^{10})$ by reducing the number of nodes to N/R and the number of links to L/R, where R is the number of areas, and this is significantly smaller than the routing reconfiguration method without hierarchically divided areas.