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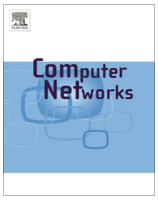

Review Article

An efficient traffic engineering based on multi-topology routing for future internet

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ABSTRACT

There is no doubt that the future Internet traffic will be dominated by the multimedia services. However, their strict quality of service requirements, as well as bursty nature, are not well suited for the best-effort delivery of the Internet infrastructure. In this paper, we propose a novel multi-topology routing based traffic engineering approach. The scheme can provide simple, yet efficient, solution with the near-optimal network performance even under unpredicted traffic spikes. While taking into account the flow's delay restriction in routing, the proposed scheme can also provide link failure resiliency. First, based on a proposed algorithm, fully edge-disjoint logical views of a network are extracted in a way that the delay of the longest path is upper bounded. Then, by using the master–slave optimisation problem, the proposed scheme selects the longest acceptable path for each traffic type. This can guarantee that the shortest paths are always available and can be used by the most legitimate traffic in the network. We prove that finding the multiple disjointed logical topology is NP-hard. Therefore, we present heuristic algorithms to handle the problem. Using extensive evaluations based on real and arbitrary networks and traffic matrices, we show that our scheme can achieve efficient resource utilisation with regards to flows' delay requirement.

1. Introduction

While ever growing multimedia applications such as IPTV and video-telephony have become ubiquitous, the need to migrate from a best effort service model to an integrated service model seems inevitable for future Internet architectures. The Internet owes its success to its naive operation, routing all requests along the shortest path based on predefined link weights. However, that sort of simplicity comes at the cost of optimality and the approach cannot effectively utilise network resources for today's traffic demand.

Achieving optimal link utilisation, or more accurately the near-optimal link utilisation due to the NP-hard nature of the problem [1], requires link weights adjustment based on a network-wide view of the traffic and topology within a domain. Such adjusted-weights would result in a balanced load distribution across all links and total cost minimisation. The procedure, that takes the traffic matrix as an input and returns an optimal set of link weights for a given topology as an output, is called traffic engineering (TE).

Of all of the available TE techniques, many of them rely on the offline methods, where long-term average traffic demands over multiple days or potentially months are used as an input. Though simple to implement, their output might cause a suboptimal or even an inadequate load distribution due to the highly unpredictable variation of traffic demand. Consequently, the next step would be to use online TE that reacts to the real-time traffic demand [2,3]. Making link weights sensitive to the current load of network, however, requires the flooding of new link weights throughout the network, causing route instability and transient forwarding loops [4,5].

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To account for the effect of the on-the-fly link weight changes, the multi-topology routing (MT-Routing) [6,7] has been used excessively in recent years [8–10], especially in the context of TE [11–13,4,5,14]. MT-Routing provides routers with multiple *logical* views of the network's physical topology, each one with an independent set of link weights. A separate routing table is maintained for each topology, allowing routers to leverage the high flexibility in better path selections.

The basic properties of the existing algorithms for building logical topologies are as follows: for each link in the network there exists a topology where the link is excluded. At the same time, they try to reduce the chance of the link being selected by all the remaining logical topologies. Consequently, the result would be multiple logical topologies with overlapped parts. Since each logical topology has a separate routing table and updating process, any decrement in its number and size can have a significant signalling and routing overhead reduction, and therefore, is of prime importance in this work.

Although having multiple logical topologies offers a high level of flexibility in path selection for different traffic types, they still share the same physical topology. Therefore, while concerning overall resource utilisation is still indispensable, carriers have to guarantee that a topology selected to carry a given flow satisfies its service level agreement (SLA) requirements. Having multiple logical topologies with the set of link weights that minimise the overall cost of the network yet breach the SLA carrier commits to its customers makes the solution impractical in an operational network.

Based on this insight, the approach of this work differs from the existing proposals in that, the proposed scheme focuses on an edge-disjoint logical-topologies construction and the SLA based traffic assignment. However, contrary to the current routing protocols, that send packets along a best possible route, the proposed approach always selects the last possible one, the route with the longest possible delay that does not breach the SLA. To this end, heuristic algorithms to decompose a given physical topology to multiple edge-disjoint logical ones are introduced, wherein each traffic class is assigned to one of them. The traffic demand between each Origin–Destination (O–D) pair is a combination of different traffic classes, each with its own SLA requirement defined here as the average end-to-end delay across all O–D node pairs [15]. Therefore, the proposed approach assigns the high-priority traffic with a very tight requirements, e.g., voice, to a logical topology containing the shortest path between the pair. Unlike the high-priority traffic, which has a stringent delay requirement, low-priority traffic (e.g., data) can survive gradual degradation as the network performance reduces. Therefore, they can be mapped to a topology containing the longest path between the pair. In order to ensure a minimum acceptable service level for low-priority traffic, the proposed algorithm bounds the worst-case performance, guaranteeing that a longest path delay cannot be more than the maximum acceptable delay. If the number of disjoint topologies was more than two, other traffic types can be defined and assigned to one of the remaining topologies. The proposed algorithm can be deployed in each router independently. Moreover, having fully edge-disjoint logical topologies can enhance failure resiliency, making it more robust to changes in the network status.

The rest of this paper is organised as follows. The system model and problem definition are introduced in Section 2. The proposed algorithms for building disjoint routing topologies and selecting the best one based on flow requirements are proposed in Section 3. The numerical experiments are then summarised in Section 4, followed by the conclusions in Section 5.

2. System model and problem definition

A network is represented by a weighted directed graph $G = (V, E, c, d)$, where V is the set of nodes and E is the set of links. The delay and capacity of a link (i,j) from node i to node j are represented by $d(i,j)$ and $c(i,j)$, respectively. Let p be a path between an origin s and a destination t, the delay of path p, as an additive metric, can be expressed as follows:

$$d(p) \triangleq \sum_{(i,j)\in p} d(i,j) \qquad (1)$$

The traffic matrices reflect the volume of traffic $R = \{r_{st} \mid s,t \in V\}$, where r_{st} is the traffic demand between a given O–D pair $s \to t$. For each pair node, a link-based routing x is defined by a set of variables $x = \{x_{ab}(i,j) \mid a,b,i,j \in V\}$, where $x_{ab}(i,j)$ is a fraction of traffic demand between a pair $a \to b$, that goes through the link (i,j). The flow conservation and non-negativity constraints on the variable x_{ab}, can be defined by the following equations:

$$\begin{cases} \forall\ i,j \neq a,b: & \sum_{(i,j)\in E} x_{ab}(i,j) - \sum_{(j,i)\in E} x_{ab}(j,i) = 0 \\ \forall\ a \neq b: & \sum_{(a,j)\in E} x_{ab}(a,j) - \sum_{(j,a)\in E} x_{ab}(j,a) = 1 \\ \forall\ a \neq b: & \sum_{(b,j)\in E} x_{ab}(b,j) - \sum_{(j,b)\in E} x_{ab}(j,b) = -1 \\ \forall\ (i,j) \in E: & 0 \leqslant x_{ab}(i,j) \leqslant 1 \end{cases} \qquad (2)$$

Traffic engineering usually considers a link-cost function $\Phi(f_{i,j}, c(i,j))$ that is an increasing function of the load $f_{i,j}$ on each link (i,j). While $\Phi(f_{i,j}, c(i,j))$ can represent any increasing and convex objective function, in this work the objective is to keep the load on a link within its capacity which consequently reduces the cost $\Phi(f_{i,j}, c(i,j))$. More precisely, the defined cost function $\Phi(.)$ adds up the cost of all the links, where the cost of a link is obtained from the relationship between the link capacity $c(i,j)$, and its current load $f_{i,j}$. Based on the experimental study conducted in [1], the cost function is defined as a piecewise-linear approximation of the $M/M/1$ delay formula, such that:

$$\Phi(f_{i,j}, c(i,j)) = \begin{cases} f_{i,j} & \frac{f_{i,j}}{c(i,j)} < \frac{1}{3} \\ 3f_{i,j} - \frac{2}{3}c(i,j) & \frac{1}{3} \leqslant \frac{f_{i,j}}{c(i,j)} < \frac{2}{3} \\ 10f_{i,j} - \frac{16}{3}c(i,j) & \frac{2}{3} \leqslant \frac{f_{i,j}}{c(i,j)} < \frac{9}{10} \\ 70f_{i,j} - \frac{178}{3}c(i,j) & \frac{9}{10} \leqslant \frac{f_{i,j}}{c(i,j)} < 1 \\ 500f_{i,j} - \frac{1486}{3}c(i,j) & 1 \leqslant \frac{f_{i,j}}{c(i,j)} < \frac{11}{10} \\ 5000f_{i,j} - \frac{16{,}318}{3}c(i,j) & \frac{11}{10} \leqslant \frac{f_{i,j}}{c(i,j)} \end{cases} \qquad (3)$$

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