Understanding the interaction between overlay routing and Traffic Engineering *

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ABSTRACT
We study the interaction between optimal routing overlay and Multiprotocol Label Switching (MPLS) Traffic Engineering (TE) in a single Autonomous System (AS). Our work is motivated in part by the work of Qiu *et al* [1], in which the interaction between overlay selfish routing and TE is brought up. However, our work is different in that [1] assumes each overlay user controls an infinitesimal amount of traffic demand and makes routing decisions independently. We study a single large scale and centrally controlled overlay network that controls a *non-negligible portion* of traffic demand and does optimal routing on application level. Akamai exemplifies this type of overlay. We further assume that the proportion of overlay traffic is significant enough to influence the routing decisions of TE.

We formulate this interaction as a two-player non-cooperative non-zero sum game, where TE's objective is to minimize the network cost as a whole, and an overlay optimizer is to minimize the overall delay for its own traffic on top of the routings set by TE. Strategies of overlay are the flow allocations of overlay traffic on logical (application) level, whereas, strategies of TE are the flow allocations of all traffic demand on physical level. The routing decisions (strategies) of overlay are essentially the inputs to TE (interpreted as traffic demands), and in turn, routing decisions (strategies) of TE will influence the future routing decisions made by overlay by affecting the costs or delays on logical links.

The key contributions and results are summarized as follows.

We focus on two types of games. In the first type of game, *Nash routing game*, overlay and TE are of equal status, and the interaction process is a *best-reply dynamics* in which each player takes turn to compute their optimal strategies based on the response of the other player in last round. Our conclusions of this game are that overlay routing will never improve the performance of TE if TE uses MPLS (analytically proved), and in most cases, TE's cost will be increased a lot in the interaction with overlay, and the cost increase of TE is a function of the percentage of overlay traffic. If overlay traffic is about 50% of total traffic, overlay's influence on TE's performance achieves the largest. These conclusions are confirmed in experiments in a 14-node tie-1 ISP topology. To illustrate the interaction process, for a simple network, we give an analytical proof on the existence, uniqueness and global stability of Nash equilibrium (NEP.) For general networks, we show experimentally that the selfish behavior of overlay can cause huge cost increase and oscillations to the whole network.

Even worse, we have identified cases, both analytically and experimentally, where the overlay's cost increases as the Nash routing game proceeds even though overlay plays optimally based on TE's routing at each round. Thus, it may not be wise for an overlay to always optimize its routes each time TE does physical routings. This observation is consistent with the inherent inefficiency characteristic of NEP and is of practical importance to an overlay routing structure.

In the second type of game, *Stackelberg routing game*, we propose that overlay play as a leader to completely eliminate oscillations and optimize its own performance. Since solving a static Stackelberg game (a bi-level programming problem) is NP-hard, we provide a gradient projection search heuristic to solve for Stackelberg strategy. Our preliminary results show that it is very promising to use this heuristic to solve for the approximate Stackelberg routing strategy for an overlay network.

Finally, we further study the games in which overlay has only limited information. We also discuss other issues on: The interaction between multiple overlays; Frequency and time scale of game playing process.

*A poster version of this paper is available at `www-net.cs.umass.edu/~honggang/overlay_poster.pdf` A full version of this paper is available as a technical report at `www-net.cs.umass.edu/~honggang/overlay.pdf`

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1. REFERENCES

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