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A coalitional game approach on improving interactions in multiple overlay environments

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ABSTRACT

The overlay network has been widely deployed by Service Providers (SPs) to provide services. Since there are multiple SPs built upon the same Internet Service Provider (ISP), their overlays are co-existing and may interfere with each other. The selfishness of overlay may lead to sub-optimal performance and traffic arrangement dilemma for overlays. To optimize the performance of overlays and maximize the benefit of SPs, we propose a cooperative overlay optimization approach, in which overlays can form coalitions freely for the purpose of cooperation. This approach performs a two-step process: the coalition optimization process and the coalition formation process. Several models are applied to describe these two processes. The overlay routing problem of a coalition, the revenue allocation problem, and the convergence problem of coalition formation are analyzed and solved. In the coalition formation process, the relationship between co-existing overlays is also analyzed. Simulations are performed to evaluate our approach, which is proved to be effective on improving the performance and balancing the fairness of co-existing overlays.

1. Introduction

The overlay network is a logical computer network built upon the traditional physical network, which can provide new functionality without modifying the underlay network. This characteristic makes it popular for Service Providers (SPs) to use overlays to provide services. Thus, a variety of overlays have been widely deployed by SPs to provide different kinds of services, such as, P2P networks, resilient overlay networks [1], multicast [2], and content delivery networks (CDN).

These SPs acquire physical network resources from ISPs, so that they can build their overlays upon the native network to provide services. As the physical network resources of an ISP may be used by several SPs, there may be multiple overlays deployed on the same underlay network. For the underlay network, these overlays have the equal rights to use the resources to provide services. They are said to be "co-existing", because they may share the same physical resources, for example, they may have their overlay nodes deployed on the same physical node; or their overlay routes may overlap with each other. Through the shared physical resources, these co-existing overlays may interfere with each other. An overlay will compete for physical resources with other overlays to achieve a better performance, which may cause the performance degradation of other overlays. Unfortunately, the competition between co-existing overlays may result in a sub-optimum performance of the whole network and causes continuous oscillation of the overlay routing. Since SPs can have their overlays built upon underlying overlays, the resource competing problem is also occurred in SPs that provide Over-The-Top (OTT) services.

There are cooperative solutions on improving the performance of overlays. But the cooperation between overlays can hardly be stabilized. During the cooperative routing process,

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an overlay may cheat while others act cooperatively. Therefore, the cooperation may be collapsed once the cheater is revealed. Although the global optimal traffic arrangement improves the performance of whole network; the performance of some overlays may be sacrificed. Obviously, these sacrificed overlays may drop out of the global optimization process. To make the cooperative traffic arrangement more realizable, we come up with two methods in this paper.

In the first method, although co-existing SPs may not be able to work together to optimize the global performance, they can form small groups and cooperate to optimize the performance of the group they belong to. Of course, every SP would like to join the group that benefits it most, and it can join or leave a group freely. If an SP does not act cooperatively in a group, other SPs can also kick it out. It is possible that co-existing SPs reach a stable state of group formation where every SP is satisfied with its benefit.

In the second method, the sacrificed overlays receive some compensation, if they participate in the global optimization process. Although the trade of the performance between overlays may be unrealizable, the trade of the profits of SPs is simple and easy. Since the profit of a SP is positively correlated to the performance of its overlay, the compensation of a sacrificed overlay can be done financially. When all the overlays cooperate and work together, the revenue of all SPs should be shared together. So, the amount of revenue assigned to a SP should be related to how much its overlay contributes to optimizing the performance of the whole network. The question is how to decide the amount of revenue an overlay should share. In the global optimization process, the set of all co-existing overlays can be treated as a big coalition. The Shapley value [3] is introduced to decide the shares of revenue since it can improve the fairness between SPs and guarantee the stability of the coalition. Note that, this method can also be applied to the small coalitions in the first method.

Combining these two methods, we come up with a cooperative overlay optimization approach. In this approach, the co-existing overlays periodically perform a two-step process to optimize their own benefits. The first step is the coalition formation process. During the coalition formation process, each overlay attempts to join the coalition that benefits its SP most according to the evaluation. After the coalition formation process is done, each coalition performs the coalition optimization process. The overlays in the same coalition perform the cooperative routing to maximize the profit of the coalition and share the revenues.

The rest of this paper is organized as follows. Section 2 introduces the related work. Our cooperative overlay optimization approach is described in Section 3. Section 4 theoretically analyzes and solves the coalition optimization problem, the revenue allocation problem, and the coalition formation problem. In Section 5, we describe how to apply our approach in a real scenario. And Section 6 shows the simulation results to illustrate the effectiveness of our proposed approach. Finally, conclusions are made in Section 7.

2. Related work

In this section, the researches on multiple overlay environments are summarized. Firstly, we introduce the studies on the interactions in multiple overlay environments. Then, we show a variety of cooperative solutions to different problems revealed by the researchers.

2.1. The interactions in multiple overlay environments

In multiple overlay environments, there are mainly two kinds of interactions. One is the cross layer interaction between overlay networks and native network, which is also called as “vertical interaction”. Another is the horizontal interaction which denotes the interaction between co-existing overlay networks.

The cross layer interaction between overlay networks and native network firstly attracts the researchers’ attention, and the game theory has been widely used to study this kind of interaction. In [1], the authors analyze the interference between overlay routing and traffic engineer (TE). A two-player game is used to formulate the conflict between their objectives, in which overlay routing is concerned with its own optimal routes, while TE is interested in the performance of the whole network. The misalignment between their objectives leads to oscillations and performance degradation of the entire network. The authors in [4] demonstrate that overlay routing results in a poor performance of IP-based TE. In [5] and [6], the authors focus on the content distribution network, and the interaction between content distribution and TE is analyzed. The authors in [5] use three game-theoretic models to show how the information exchanging impacts the performance of server selection and TE. In [6], the authors model the interaction between content distribution and TE. Then, they study several scenarios and analyze how the congestion signal from the underlay network interferes with the server selection of overlay users.

There are also researches in the horizontal interaction in the multiple overlay network environments. The impact of selfish overlay routing on the network was first discussed by the authors in [7]. They point out that the total latency achieved by the selfish overlay routing is much higher compared with the optimal routing. Qiu et al. [8] analyze the interaction between multiple co-existing overlays when performing the selfish routing. They point out that the selfish routing can achieve close-to-optimal performance at the expense of overloading certain links. The Price of Anarchy caused by the selfish overlay routing is analyzed in [8] and [9]. In [10], Keralapura et al. analyze the scenarios that lead to the oscillations of overlay routing, when multiple routing overlays inadvertently schedule their own traffic without the knowledge of one another. The non-cooperative interaction between the P2P overlay and TE is studied by Wang et al. [11]. They point out that the non-cooperative interaction leads to a non-optimal performance in both layers. Jiang et al. [12] model the interaction between co-existing overlays as a non-cooperative strategic game. They prove that when all the overlays apply the overlay optimal routing, their performance will be sub-optimal. To solve the issue, a pricing scheme is proposed for overlays to achieve the global optimum. But it is difficult to realize since overlays are required to have a full understanding of the underlay network topology. Due to the unfairness between co-existing overlays, not every overlay can benefit from the global optimal, thus it is difficult to deploy. In [13], the authors study the