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Pricing strategies for differentiated services content delivery networks ☆

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Abstract

In order to reduce the user latency, the web sites disseminate some of their information to surrogate caches located closer to the users. We discuss a simple differentiated service type architecture for content delivery networks. A pricing scheme is next proposed to complement this architecture and provide fair service to the subscribed publishers. Then, we show that the suggested pricing scheme is also the optimal (revenue maximizing) pricing scheme for a monopolistic surrogate. We investigate the performance of the pricing scheme in a duopoly and show that under certain conditions the competition results in peering of the surrogates. Finally, we suggest methods to determine the optimal number of service classes offered to the users.

Keywords: Network pricing; Market-based resource allocation; Game theoretical modeling of communication networks; Internet service classes under competition

1. Introduction

The Internet is becoming more commercially oriented each passing day, and the effects of the user service quality is becoming more prominent. In the new Internet *economy*, the web sites (origin servers) are the *publishers* of the Internet content. They appear as businesses generating their revenues from the content that they provide. Usually,

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the more popular a web site is the more revenue it generates. Meanwhile, the popularity of a web site depends among other things on the high quality (quality can be measured in terms of delay, delay jitter or bit rate, etc.) delivery of its content. In order to prevent deprivation of quality of service due to server and Internet congestion, the origin servers historically used proxy caches located closer to the users for the delivery of their content. However, until recently the caches are used in a best effort fashion with a single quality of service. Several Content Distribution Networks (CDNs) such as Akamai [26], Edgix [27] and DigitalIsland [28] began offering caching services with service level agreements (SLA) to the publishers. CDNs provide the publishers a reliable and robust surrogate caching server infrastructure, which covers most of the globe. The origin servers 'rent' portions of the caching capacity from the CDN's caching servers and receive varying benefits depending on the surrogates' locations, capacities and the user request arrival rates.

1.1. Contributions and organization of the paper

This paper investigates the optimal pricing problem for content delivery in the Internet, when a surrogate offers several service classes to the publishers with varying qualities of service. The qualities of service classes differ according to the amount of resource (caching space, bandwidth, etc.) allocated to each service class as well as the number of publishers subscribing to each class. All the publishers subscribing to the same service class receive equal share of the resource. In this paper, we only consider static resource allocation, since dynamic resource allocation is both complex and perhaps unnecessary for Internet caching. Note that the demand for caching resources is much more stable over time. Additionally, in order to promote the integrity of publishers, the surrogate does not penalize premium class publishers by charging them higher price compared to lower classes when the allocated resource to premium class publishers drops to the level lower class publishers attain.

Optimal pricing problem has several parts: determining the optimal number of service classes given the publisher subscription statistics, finding the optimal resource allocation for each service class and finally devising an optimal resource tariff. Thus, in order to solve this complicated problem we divide it into three sub-problems. After discussing our model in Section 2, in Section 3, we find the optimal tariff for a monopolist given the number and type of service classes, and the resource allocation for each class. Then, in Section 4, we determine the optimal resource allocation for each service class given the number service classes, and using the optimal tariff determined in the Section 3. Finally, in Section 6, we investigate the answer to the question of how many service classes the surrogate should offer to maximize its benefit. The paper also provides a game-theoretic discussion of a duopoly of competing surrogates in Section 5, and the result suggests that one of the Nash equilibrium solutions is the peering of the surrogates.

We summarize our results and conclude in Section 7. In order to improve readability, we moved most of the proofs to the appendices.

1.2. Related work

Internet pricing has received much attention recently, e.g., see [11–14,17,21]. In these studies, dynamic pricing schemes were suggested to prevent congestion in the Internet. Such schemes proved to be highly complex for implementation in the current Internet. Recently, Kelly et al. [22], Johari and Tsitsiklis [23], and Hajek and Yang [24], all considered bandwidth sharing game where the users bid for the resources in the network. In Kelly et al., users are price takers, i.e., they ignore their own effect on the price. On the other hand, Johari and Tsitsiklis considered a setting where users are price anticipators, i.e., they take the price formula into account when determining their bids. In the work of Johari and Tsitsiklis, users bid for each link on the path. Finally, Hajek and Yang considered a similar game as Johari and Tsitsiklis did, but in their setting users submit a single total bid for the all the link resources on the path and the network allocates the rates in a weighted proportionally fair fashion.

Unlike the previous work, which investigated the outcome of the game played among users for