Caching Games between Content Providers and Internet Service Providers

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ABSTRACT

We consider a scenario where an Internet Service Provider (ISP) serves users that choose digital content among M Content Providers (CP). In the status quo, these users pay both access fees to the ISP and content fees to each chosen CP; however, neither the ISP nor the CPs share their profit. We revisit this model by introducing a different business model where the ISP and the CP may have motivation to collaborate in the framework of caching. The key idea is that the ISP deploys a cache for a CP provided that they share both the deployment cost and the additional profit that arises due to caching. Under the prism of coalitional games, our contributions include the application of the Shapley value for a fair splitting of the profit, the stability analysis of the coalition and the derivation of closed-form formulas for the optimal caching policy.

Our model captures not only the case of non-overlapping contents among the CPs, but also the more challenging case of overlapping contents; for the latter case, a non-cooperative game among the CPs is introduced and analyzed to capture the negative externality on the demand of a particular CP when caches for other CPs are deployed.

CCS Concepts

•Networks → Network economics; •Theory of computation → Solution concepts in game theory;

Keywords

Coalitional game theory, Shapley value, Nash Equilibrium

1. CONTRIBUTIONS

The goal of our work (the full version has been selected to be published in [1]) is to analyze a business model where the ISP and the CPs collaborate by sharing the cache cost/ profit deployment. We use coalitional game theory to model the interactions between them.

Initially, we consider a scenario with one ISP that serves J users and one CP that offers additional content to these users. We compute the profit for the ISP and the CP, expressed as a utility function that captures the difference between the income minus the expenses. Then, we examine the impact of caching on the utility functions of the ISP and the CP. We show that the deployment of the cache incurs always a positive externality for the income of CP, since his profit will increase (in the worst case, it will remain stable). On the other hand, the deployment of the cache is beneficial for the ISP if and only if the backhaul bandwidth savings are larger than the cache cost deployment.

We propose a different business model where the CP and the ISP are willing to split the cost/profit that arises due to caching. Therefore, they are willing to form a coalition; We compute the Shapley value showing that, in our model, the ISP and the CP share equally the additional cache cost/profit. Then, we analyze the stability of the Shapley value, showing under which conditions it belongs to the core of the game; if this is the case, neither the ISP nor the CP have motivation to leave the coalition. Finally, we compute the optimal caching policy that maximizes the revenue of both the ISP and the CP.

We then examine the more general case, where there is a unique ISP and M CPs. A key issue is that the caches of the other CPs create a negative externality to the demand of the CP i; there is a coalitional game between the CP i and the ISP. As previously, we compute the Shapley value. Then, we analyze the non-cooperative game that arises due to the competition among the CPs. We prove that this game admits always a Nash Equilibrium (NE). Finally, we examine the uniqueness of the NE and we make the following contributions: i) We prove a necessary and sufficient condition for the uniqueness of the NE. ii) We propose a best-response dynamics scheme, where each CP i updates iteratively his cache size C_i aiming at maximizing his utility function, that is guaranteed to converge to the unique NE. iii) Simulations show that the scheme converges fast to the NE.

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3. REFERENCES

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