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Microeconomics-based resource allocation in overlay networks by using non-strategic behavior modeling

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ABSTRACT

Behavior modeling has recently been investigated for designing self-organizing mechanisms in the context of communication networks in order to exploit the natural selfishness of the users with the goal of maximizing the overall utility. In strategic behavior modeling, the users of the network are assumed to be game players who seek to maximize their utility with taking into account the decisions that the other players might make. The essential difference between the aforementioned researches and this work is that it incorporates the non-strategic decisions in order to design the mechanism for the overlay network. In this solution concept, the decisions that a peer might make does not affect the actions of the other peers at all. The theory of consumer-firm developed in microeconomics is a model of the non-strategic behavior that we have adopted in our research. Based on it, we have presented distributed algorithms for peers' "joining" and "leaving" operations. We have modeled the overlay network as a competitive economy in which the content provided by an origin server can be viewed as commodity and the origin server and the peers who multicast the content to their downside are considered as the firms. On the other hand, due to the dual role of the peers in the overlay network, they can be considered as the consumers as well. On joining to the overlay economy, each peer is provided with an income and tries to get hold of the service regardless to the behavior of the other peers. We have designed the scalable algorithms in such a way that the existence of equilibrium price (known as Walrasian equilibrium price) is guaranteed.

1. Introduction

1.1. Motivation

Application layer multicasting is a solution concept in order to disseminate the content (such as videos and teleconferences) in large scale decentralized peer-to-peer networks. To this end, an overlay topology (typically, a tree) is formed on top of the underlying physical network in which each node represents a peer and each edge represents the flow of content that is transmitted between each pair of nodes via a TCP connection. Also, the root of the multicast tree represents the original service provider of the network.

Recently, the overlay networks have attracted the attention of the community since they are easier and more efficient to deploy in comparison with the networks that use IP multicasting. The multi-rate overlay networks are characterized by the fact that the content can be downloaded by the peers at different rates depending on the downloading capacity of the

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peers. Since the peers are selfish users who typically belong to various administrative domains, they do not tend to cooperate with each other. Thus, it is more likely that a peer downloads the content from its upstream peer rather than uploading to the downstream peers. This behavior can potentially degrade the overall throughput of the overlay network. Clearly, every proposal in order to maximize the aggregate throughput of the overlay network must also take into account the selfishness of the peers.

We believe that the so called problem could be investigated by microeconomics theories. In microeconomics, the goal is to maximize the aggregated utility of the consumers in conjunction with maximizing the profit of the firms as the selfish agents of the system. In our mapping, the service provided by the overlay network can be viewed as the commodity and the behavior of the overlay peers can be mapped to that of the consumers in the economy. Also, the origin server and the peers who forward the content to their downstream peers can be thought as the firms of the economy.

1.2. Challenges

In the literature, utility-based approaches have been investigated for constructing bandwidth-efficient overlay trees. In such solutions, each peer is associated with a utility which is a function of its downloading rate. It has been shown in [1–3] that finding among all possible trees, the one with optimal maximum utility or maximum bandwidth is an NP problem. To address the selfish behavior of the overlay peers, some works have used game theoretic approaches [4–9]. In these proposals, the peers of the network are treated as game players with conflicting interests regarding the allocated bandwidth. The game theoretic approaches, fall into the category of "*strategic behavior modeling*" in which the players seek to maximize their utility regard to the decisions that the other players might make. Also, another category of proposals exist in which the selfishness of the peers is controlled by means of distributed pricing [10,11].

1.3. Contributions

We shall not try to solve the NP problem of constructing the multicast tree here. Instead, we assume a given topology setting and try to exploit the inherent selfishness of the peers in such a way that the ultimate outcome still leads to maximization of the aggregated utility of the users of the overlay network.

A major contribution of this work is that unlike the game theoretic approaches, here the decision that a given peer might make, does not depend on the decisions taken by the other peers. Roughly speaking, our work falls into the category of "*non-strategic behavior modeling*" for which we have adopted the theory of *consumer-firm* developed in microeconomics. We have developed scalable self-organizing algorithms for joining/leaving the peers to/from the overlay network in which each peer is provided with an income. Upon joining or leaving, the algorithms try to find the equilibrium price in such a way that the total demanded bandwidth of the system equates its total supplied bandwidth. In microeconomics terminology, this method of finding equilibrium point is known as "*Walrasian general equilibrium.*" To the best of our knowledge, there has been no investigation of designing the overlay networks based on the concept of the demand–supply theory in the sense of the Walrasian general equilibrium model of microeconomics.

The remainder of the paper is organized as follows: Section 2 introduces the model of the overlay network. Section 3 proposes the non-strategic behavior model developed for the overlay network. Section 4 presents the algorithms of bandwidth allocation based on the developed non-strategic behavior model of microeconomics. Section 5 presents the experimental analysis of the system and discusses the scalability issues. Finally, we discuss the related researches in Section 6, and conclude in Section 7.

2. The model of the overlay network

We consider an overlay network consisting of an origin server and V peers denoted as $\mathscr{V} = \{1, 2, \ldots, V\}$. The multicast tree consists of the origin server as the root, a set of peers, and a set of physical links. The physical links are in fact the physical connections either the router-router connections, or the router-peer connections. Let us suppose that the overlay network consists of L physical links, denoted as $\mathscr{L} = \{1, 2, \ldots, L\}$. The capacity of each link $l \in \mathscr{L}$ is denoted as c_l. Fig. 1 shows a typical overlay network including of six peers ($V = 6$) and eight physical links ($L = 8$). The flow of the content is started from the origin server (denoted as the node 0) and is forwarded by the peers. Every node, apart from the leaf nodes, forwards the stream via unicast in a peer-to-peer fashion.

Fig. 2 shows the multicast tree concerning to the example of Fig. 1. We represent the directed graph of the multicast session by a $(V+1) \times (V+1)$ adjacency matrix, denoted as $\mathbf{A}$. The $\mathbf{A}_{i,j}$ element of the matrix $\mathbf{A}$ denotes the flow that is originated from the node i and is terminated in the node j, namely $f_{i,j}$. Also, $x_{i,j}$ denotes the rate of the flow $f_{i,j}$. We put $\mathbf{A}_{i,j} = 1$ whenever there is a flow and zero otherwise. The adjacency matrix of the multicast session, shown in Fig. 2, is as follows