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A Study on Latency Minimization in Selfish Overlay Routing by Cost Pricing

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ABSTRACT

A central problem arising in the management of a large network is that of routing traffic to achieve the best possible network performance. The initial study was based on the optimization of latency and network utilization of a selfish overlay routing using Nash equilibrium. It is well known that the outcome of selfish routing using Nash equilibrium does not minimize the total latency and can be improved upon with coordination and that marginal cost pricing. The principle of marginal cost pricing assumes that taxes cause no disutility to network users. We propose to use a market-driven approach to regulate the behavior of selfish nodes that either provide or consume services. For minimizing the total latency we introduce taxation for each edges provided by a Reinforcement Learning algorithm. We consider strategies for pricing network edges to reduce the cost of Nash equilibrium. Since levying a sufficiently large tax on an edge effectively removes it from the network, our study generalizes previous work on network design.

Keywords: Selfish Routing, Network Pricing, Nash Equilibrium, Reinforcement Learning

1. INTRODUCTION

Selfish overlay networks consist of autonomous nodes that develop their own strategies by optimizing towards their local objectives and self-interests, rather than following prescribed protocols. Latency is the delay between the initiation of a network transmission by a sender node and the receipt of that transmission by a receiver node. The inefficiency of selfish routing motivates the introduction of marginal cost pricing. The principle of marginal cost pricing asserts that on each edge, each network user on the edge should pay a tax equal to the additional delay its presence causes for the other users on the edge. Market-driven approach is used in this paper which considers service providers and consumers providing and receiving services respectively. A decentralized algorithm was designed that uses Reinforcement learning to help selfish nodes to incrementally adapt to the local market, and to make optimized strategic decisions based on past experiences.

2. RELATED WORK

The degradation in network performance caused by the selfish behavior of non-cooperative network users was studied. We consider a model of selfish routing in which the latency experienced by network traffic on an edge of the network is a function of the edge congestion, and network users are assumed to selfishly route traffic on minimum latency paths. The quality of a routing of traffic is measured by the sum of travel times, also called the total latency. The outcome of selfish routing, Nash equilibrium does not in general minimize the total latency; hence, selfish behavior carries the cost of decreased network performance. In many settings network users are free to route their traffic in a selfish manner, without regard to the total latency. A Nash equilibrium then corresponds to a flow in which all flow paths between a given source and destination have minimum latency—in a flow without this property, some traffic can improve its travel time by switching from a longer path to a shorter one. Traffic flows at Nash equilibrium do not in general minimize the total latency incurred by network users. The various models are used like for Linear functions the equation is $ax + b$ and the price of anarchy is $4/3 \approx 1.333$. for the Quadratic function the equation is $ax^2 + bx + c$ and the PoA is $3\sqrt{3}/(3\sqrt{3} - 2) \approx 1.626$. For the Cubic function the equation is $ax^3 + bx^2 + cx + d$ and the PoA Is $4\ 3\sqrt{4}/(4\ 3\sqrt{4} - 3) \approx 1.896$. For M/M/1 Delay Functions the equation is $(u - x)^{-1}$ The price of anarchy for common classes of edge latency functions. The parameters u and ó are the expectation and standard deviation of the associated queue service rate distribution. [1]

To seek a flow satisfying all our objectives between origin-destination pair's link latencies with assumptions, load-dependent latencies, a decentralized control, rational and selfish users Routing becomes tough. Say, each user controls a negligible amount of flow equilibrium always exists. If f is a Nash flow, all si -ti paths to which f assigns a positive amount of flow have equal latency In a partially decentralized control, "Followers" selfishly route flow(Nash flow) while the "Leader" centrally determines only an á-fraction of the demand (Stackelberg flow). Stackelberg routing is used in public transport, Navigation systems and telecom networks. Any strategy has PoA at least proportional to, a function of the size of the network, makes a good and tighter bound for SCALE. The conclusions on Stackelberg routing is that there is no constant fraction of "altruistic" users suffices to enforce a constant PoA [2]

One of the important problems in managing networks is to route traffic so as to make the latency experienced by the average user small. This problem can be solved effectively when all the traffic submits to the control of a central authority. However in large-scale decentralized computer networks (such as the Internet) is it feasible to establish such a central authority. Rather, individual users of the network have control over the paths they choose from their origin to their destination. The prevailing assumption is that users will exert this power to choose the route minimizing their individual latency, regardless of the effects that such a choice may have on other users. A natural question is then how much the average latency increases as a result of such selfish behavior, compared to a central authority balancing the latencies of different users. The ratio between the socially optimal outcome and the out come of selfish choices has been termed "Price of Anarchy" (PoA). Selfish users do not care about the social cost. Their sole goal is to select a path which minimizes their own latency. Thus, they selfishly tend to choose edges with currently lower latency, over-congesting edges which would be very fast if used in moderation. The traffic routing problem can be considered a game, and the "outcome" of this game will be a Nash Equilibrium. It is showed that if the cost functions can be arbitrary, then the price of anarchy can be unbounded, but if all functions are linear, then the price of anarchy is utmost 4/3. [3]

Selfish behavior of heterogeneous users in a network can be regulated introduction of appropriate taxation. Total latency is the sum of the latency of the user and the cost calculated based on the latency it causes others. Each user tries to selfishly route his flow so that his path cost is minimized. Traffic equilibrium is an assignment of traffic to paths so that no user can unilaterally switch her flow to a path of smaller cost. Wardrop's principle for selfish routing postulates that at equilibrium, for each origin-destination pair the travel costs on all the routes actually used are equal, or less than the travel costs on all nonused routes. The minimum-latency is reduced using a pair of primal-dual linear programs. The latency for a path is defined as lP (f) := le(fe). The users have the Right to use the path.

path cost(P) := latency(P) + $a(i)$ · taxation(P). where p is path and i is class.

In the homogeneous case, $a(i) = 1$, for all i. In the heterogeneous case, $a(i)$ = different positive values for different classes. Primal-dual linear programs are used for optimization of taxes. Limited usage of generality with taxation sensitivity problem and Elastic case only for linear edge latency functions are the two drawback of this method.[4]

A model of selfish routing in which the latency experienced by network traffic was considered on an edge of the network is a function of the edge congestion, and network users are assumed to selfishly route track on minimum-latency paths. It is well known that the outcome of selfish routing Nash equilibrium does not minimize the total latency and can be improved upon with marginal cost pricing meaning charging each network user for the congestion effects caused by its presence. Intuition may suggest that taxes should never be able to improve the cost of Nash equilibrium, but the famous Brass's Paradox shows this intuition to be incorrect. A strategy for pricing network edges to reduce the cost of Nash equilibrium was considered. Since levying a sufficiently large tax on an edge electively removes it from the network, generalization of previous work on network design was done. With linear latency functions—marginal cost taxes do not improve the cost of the Nash equilibrium. The best-possible beneath from arbitrary taxes does not exceed that of edge removal. There are networks with nonlinear latency functions, however, in which taxes are radically more powerful than edge removal [5].

3. PROPOSED SOLUTION

There were two scenarios with two different networks, one when tax was paid and the other when the edge was removed while congestion takes place.

3.1. Taxation of Edges

When latency alone was considered it will be reaching the global criterion of minimum delay in a traffic flow only using taxation of users. Each time the user uses a route he has to pay tax to an upstream node. The total tax calculated for any user is based on the latency that is incurred on itself and the latency that it causes to its neighbors while it uses a particular route. We show that most of the very strong inapproximability results known for network design carry over to the problem of computing optimal taxes. In taxation, an algorithm called Reinforcement Learning algorithm for decentralization of the strategies on the market driven network was considered. Reinforcement learning algorithm is a branch of machine learning that uses past experience in optimal decision making through trial and error interactions with external environment. We find the probability of taking an action to a state. Agent incrementally improves its decision policy towards optimal based on the feedback provided by the environment known as reinforcement. E.g.: chess game- best moves.

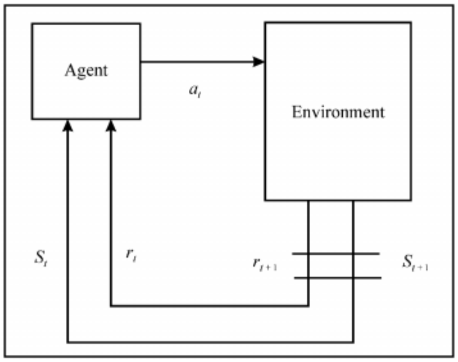

Fig 1: Reinforcement Learning

3.2. Edge Removal

While the congestion takes place, the edges are removed. This is used only for few networks which require high priorities. We prove that the maximum-possible benefit due to edge taxation is no more than what can be achieved, in the best case, via edge removal.

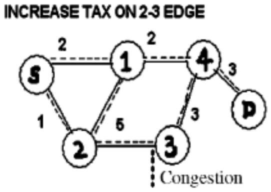

Fig 2: Taxation of Edges

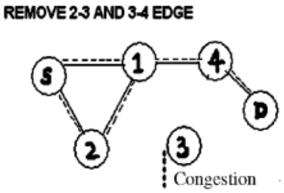

Fig 3: Edge Removal

4. ADVANTAGES

Artificial intelligence concept is used so as to reach a stable taxation schemes. The price of anarchy is also satisfied with bounded network topology. Minimization of latency was considered the main criteria so congestion can be prevented. It's used in selfish overlay networks with only required number of nodes. As it's a market driven approach it gives optimal service to consumers and good profit to service providers.

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