Oblivious AQM and Nash Equilibria *

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An oblivious Active Queue Management (AQM) scheme is one that does not differentiate between packets belonging to different flows. For example, Fair Queueing is not oblivious, while RED is. The current Internet is dominated by TCP traffic. However, there are indications that the amount of non-congestion-reactive traffic is on the rise. TCP (and in fact, any transport protocol that we are aware of) does not guarantee good performance in the face of aggressive, greedy users who are willing to violate the protocol to obtain better performance. Thus, it seems important to study scenarios where end-points are greedy and selfish, and do not follow socially accepted congestion control mechanisms.

Selfish users can be modeled using game theory. A game consists of rules and players. In the Internet game, the rules are set by the AQM policies, and the players are the end-point selfish traffic agents. A fundamental solution concept in game theory is the Nash equilibrium. In the context of our problem, a Nash equilibrium is a scenario where no selfish agent has any incentive to deviate from its current state to increase its own utility. Thus, the existence of a Nash equilibrium implies a stable state of the network in the presence of selfish users, but does not provide any clues as to how this state should be achieved.

In this work, we study the existence and the properties of Nash equilibria imposed by oblivious AQM schemes on selfish agents, which generate Poisson traffic but can control the average rate. We will restrict ourselves to AQM strategies that guarantee bounded average buffer occupancy, regardless of the total arrival rate. Oblivious AQM schemes are of obvious importance because of the ease of implementation and deployment, and Nash equilibrium offers valuable clues into network performance under non-cooperative user behavior.

Specifically, we ask the following three questions:

1. **Existence**: Are there oblivious AQM schemes that impose Nash equilibria on selfish users?

2. **Efficiency**: If an oblivious AQM scheme can impose a Nash equilibrium, is that equilibrium good or *efficient*, in terms of achieving high goodput and low drop probability?

3. **Reachability/Achievability**: How can the users / players reach the equilibrium point, if one exists?

We first derive a necessary and sufficient condition, that we call the Nash condition, for oblivious AQM schemes to impose Nash equilibria on selfish users. We show that the popular oblivious AQM strategies, drop-tail and RED, do not impose Nash equilibria on selfish users. Then we propose a variation of RED, *VLRED*, that can impose a Nash equilibrium but the utilization at the equilibrium point drops to 0 asymptotically as the number of users increases. This motivates us to develop another AQM scheme, Efficient Nash AQM (EN-AQM), which can impose a Nash equilibrium, and guarantee strict bounds on equilibrium performance; that is, provide lower bounds on goodput, bounded average delays, and upper bounds on drop probability at equilibrium. It is surprising that oblivious schemes can have such strong properties. The details can be found in a technical report [1].

We also observe that for any oblivious AQM scheme, the Nash equilibrium imposed on selfish agents is highly sensitive to the increase in the number of users, making it hard to deploy and difficult for users to converge to. This further motivates the need for protocols which lead to an efficient utilization and a somewhat fair distribution of network resources (like TCP does), and also ensure that no user can obtain better performance by deviating from the protocol. We use the term *protocol equilibrium* to describe this phenomenon. If protocol equilibrium is achievable, then it would be a useful tool in designing robust networks. This appears to be an interesting, and an open problem.

References

[1] Debojyoti Dutta, Ashish Goel, and John Heidemann. Oblivious AQM and Nash Equilibria. Technical report, USC-CS-TR-763, July 2002.

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