EVOLUTIONARY GAME AND RESOURCES COMPETITION IN THE INTERNET

Youquan Zheng, Zhenming Feng
Department of Electronic Engineering,
Tsinghua University, Beijing, China, 100084
zhengyq98@mails.tsinghua.edu.cn

Abstract

In the paper we study an evolutionary game theoretic model of the resource competition among TCP flows in the Internet. TCP algorithm can be considered as an evolutionary end-to-end flow control mechanism from the viewpoint of non-cooperative evolutionary game. Theoretical analysis and simulation results show the validity of this model.

Keywords

Evolutionary Games, Resource Competition, Transmission Control Protocol

1. Introduction

Within the past few years, there has been a rapid growth in network traffic and competition for limited network resources. There are many network resources whose performance suffers when there is overuse: the switching capacity of the routers, the memory and CPU capacity of the servers and routers, the bandwidth of the transport medium, etc. When selfish users access such resources, they take into account their own costs and benefits from the usage, but ignore the congestion, delay, or even exclusion costs that they imposed on other users.

In this paper we consider the resource competition among TCP flows in the Internet as an evolutionary game, and try to study the evolutionary behavior of the TCP control mechanism in such a competitive environment using queueing theory and evolutionary game theory. Each TCP flow in the network selects proper strategy and tries to maximize its own payoff (fitness) function in the resource competition game. Analysis results and simulation outcomes show the validity of this model.

2. Resource competition

In a resource competition environment such as Internet, every source tends to seize the maximum network resources. It may result in competition for network resources, and lead to congestion and other unwanted behavior of the network. In the current Internet, the rate at which a source sends packets is controlled by transport layer protocols such as TCP and UDP.

TCP is a window-based method in which, the window size is additively increased roughly every round trip time (RTT) until congestion is detected whereupon it is multiplicatively decreased. Congestion is detected by the loss of packets. In this paper, we investigate the resource competition among TCP sources.

Unlike TCP, UDP does not perform any congestion control, so TCP friendly congestion control schemes should be performed by the upper layer protocols. These control schemes can also be analyzed using our model.

3. Evolutionary game based model for resource competition

The traditional game theoretic approach has been used in a number of fields, including traffic control, bandwidth allocating, routing and pricing. But, the standard non-cooperative game theory assumes that the game is played exactly once by fully rational players who know all the details of the game, including each other's preferences over outcomes. As a result, the game theoretic approach is no longer valid with the increasing complexity and a growing variety of services provided in the Internet.

Evolutionary game theory, instead, imagines that the game is played over and over again, and players can be partially rational, equipped with only incomplete information in large populations. In fact, evolutionary game theory is designed to enable analysis of complex strategy interaction in the Internet nowadays.

Our evolutionary game based model consists of one population of TCP users, a state space, a stage game, and a dynamic adjustment process.

3.1. Population and state space

In this paper, we consider an evolutionary game based model in which, TCP users compete for limited network resources. So, there is only one population of the players. The strategy set of TCP users in stage game is {doubling congestion window (cwnd) per RTT in the slow-start phase, cwnd increase one packet per RTT in congestion-avoidance phase, cwnd decreases to one half of its current value}

The state space of the model is $S = \{(p,q,h): p,q,h \geq 0, p+q+h=1\}$, where (p,q,h) is the vector of probability of strategies.

3.2. Stage game and evolutionary adjustment

Evolutionary games involve strategic interaction over time. At any point in time the strategic interaction is expressed as a stage game. In our model, TCP users play the stage game when every ACK is received and every timeout is detected. The stage game played by TCP users can be defined by a fitness or payoff function, which is the mean growth rate of cwnd (p_L is the probability of packet loss, also a function of cwnd):

$$f_1(cwnd) = 1 - 2P_L \tag{1}$$

$$f_2(cwnd) = (1 - P_L - 0.5 \cdot (cwnd + 1) \cdot P_L)/cwnd \tag{2}$$

$$f_3(cwnd) = (-0.5 \cdot (1 - P_L) \cdot cwnd - 0.25 \cdot cwnd \cdot P_L)/cwnd \tag{3}$$

The dynamic adjustment process in TCP algorithm is: slow start, them, cwnd is additively increased roughly every round trip time (RTT) until congestion is detected whereupon it is multiplicatively decreased. Congestion is detected by the loss of packets.

We derived the relationship between and cwnd by using queueing theory and evolutionary game theory in a simple network topology. Its numerical evaluation is shown also in next section.

4. Numerical evaluations and simulation results

Here we consider a simple network topology: four TCP flows compete for a bottleneck router, whose FIFO size is 25.

Numerical results of equations (1-3) and are shown in Fig.1, we can see that: is a function of cwnd; strategy 1 is better than others when cwnd is less then 3 packets; strategy 2 is better than others when cwnd is between 3 and 5 packets; strategy 3 is better than others when cwnd is more than 5 packets.

Using network simulator (ns), we derive some simulation results. The numbers of slow-start packets, congestion avoidance packets and dropped packets are shown in Fig.2. it has much similar meaning with the theoretical analysis and numerical results in Fig.1.

Instead of Nash equilibrium in traditional game theory, the key concept in evolutionary game theory is Evolutionary Stable Strategy (ESS). The ESS in this simulation is (0.027,0.893,0.08), which can be calculated from the simulation data.

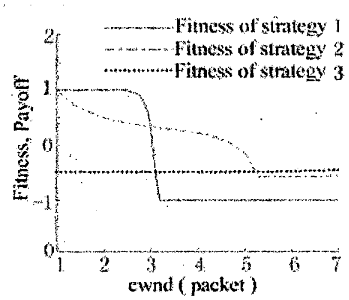

Fig.1 Fitness and P_L

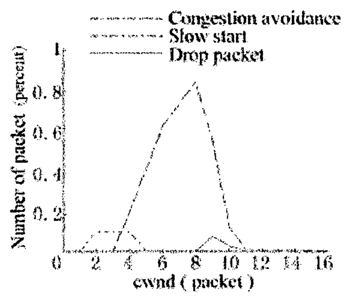

Fig.2 Simulation result

5. Conclusions

Resource allocation in the Internet is very important to both network and users. In this paper, we considered the resource competition among TCP flows as an evolutionary game, and studied the behavior of the TCP control scheme in competitive environment using queueing theory and evolutionary game theory. Analysis results and simulation outcomes show the validity of this model.

Our future work is trying to analyze the properties (such as efficiency, convergence, fairness, etc.) of the ESS and design some new control algorithms using notions of network ecology. Then, we can verify the validity of the usage of evolutionary game theory and learning theory in the Internet.