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BRIDGING AGENT-BASED SIMULATIONS AND DIRECT EXPERIMENTS: AN EXPERIMENTAL SYSTEM FOR INTERNET TRAFFIC PRICING[1]

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Abstract

A network-based experimental system for Internet traffic pricing is introduced. The system can be applied to the simulations using computer agents as well as to the direct experiments that employ human subjects. The feature of replaying the exogenous traffic patterns obtained from direct experiments allows a close comparison of the performance between the two types of experiments, leading to the new findings reported briefly in this paper.

Introduction

Evolved from traditional computer-based simulation, agent-based economic experiments are getting popular in recent years (Tesfatsion, 2000). However, the absence of behavioral and psychological factors from humans in an artificial world is still the main weakness in the creditability of the data obtained from simulations using perfect and rational agents. Evidence has demonstrated "that human behavior deviates in systematic ways from the idealized behavior attributed to expected utility maximizers in particular, and to 'rational economic man' in general" (Roth, 1996). A direct experiment using human subjects is closer to the real world, but may introduce errors caused by subjects' misbehaviors. So, filtering out noises resulted from these irrational behaviors remains the key issue in obtaining satisfactory results. To fill up the gap between simulation and direct experiment Sterman (1987) conducted a direct experiment to justify the decision rules used in game simulations. As a result of the high availability of Internet technology since 1990s, the marriage of agent-based approach and human subject based approach has imposed more challenges to experimental economists.

This paper is to report a recent effort in network traffic pricing research relevant to the above experimental methodology. One strand of the research in network traffic-pricing since 1990s is GSW network traffic pricing model, which has been tested with a simulation system (Gupta et al. 1997). Lin et al. (1999) reported a prototype network traffic-pricing system on a network platform to carry out experiments with real-time data traffic generated by software agents on client computers. Even though this agent-based experimental system produced the same outcomes as those from GSW's simulation program, the traffic-pricing scheme is still questionable because the feasibility in implementing a traffic-pricing system for real users is not proved. This paper introduces an experimental system that can be used to conduct either human subject based experiments or agent-based simulations, or a mixed type – human subject working with computer agents. Specifically, the system is capable of replaying the exogenous traffic patterns generated by direct experiments in the agent-based mode. This allows a comparative study of user performance beyond previous focus solely on traffic-pricing efficiency.

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Experimental System Design

There are four modules in the experimental system (Figure 1): 1) a virtual bandwidth server allocating bandwidth with a round-robin scheduling method for service requests; 2) a set of user-oriented applications operating on the web browser to generate service requests and display network status for request submission decisions; 3) a web-based application module as an intermediary between users and the virtual bandwidth server; and 4) a traffic load generator which is an agent for generating or regenerating network data flows.

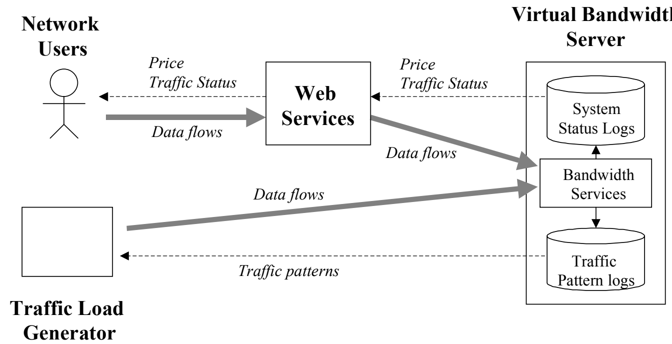

Figure 1. The Structure of the Experimental System

The experimental system is a distributed system running on a network platform. All data traffic and bandwidth services for experiments are real-time. The interaction between users and the bandwidth pricing system is a recursive three-step process. First, the virtual bandwidth server decides a bandwidth price according to current network traffic status and the average cost of service delay to users. Second, a user estimates his/her request's value, the service amount and the effect of service quality on the request. Third, the user uses the expected service delay and price information disseminated by the virtual bandwidth server to calculate the net value of the request, i.e. his/her expected utility of the service, and submit the request if the expected utility is positive.

There are two kinds of service request rates in the experiment: 1) request generation rate, the exogenous rate representing the potential maximum service demand; 2) request arrival rate, the rate that reflects the load onto the virtual bandwidth server. In direct experiments, request generation patterns are controlled by a JavaScript program at the client side. It displays a list of potential service requests on the screen periodically in a fixed length of time, e.g. every 8 seconds. The number of requests displayed each time is randomly changed in accordance with the exponential distribution. Each requests is marked with a volume, a gross value, a delay cost, and a net value range. In addition, general network status information, such as the expected unit service time and the service price, is displayed. Subjects normally check the net value range to make submission decisions.

At present, both human subject based and agent-based experiments with or without network traffic pricing have been conducted using the same bandwidth capacity preset as a T1 line (1.544 Mbps). The pricing formula derived by Lin (1999) with round-robin bandwidth scheduling is adopted.

Implications of Experiment Outcomes

Request Arrival Pattern in Direct Experiments

The critical issue in experiments is the stochastic properties of service request arrivals, which have been assumed to be a Poisson process. In agent-based experiments an algorithm has been implemented to produce service request arrivals in an approximate Poisson process (Lin 1999). The major concern in the direct experiment is whether the traffic patterns generated by human subjects also comply with Poisson process. The histogram of request arrival intervals from a typical sample data set recorded in a direct experiment shows that request arrival intervals generated by the experimental system are approximately exponentially distributed (Figure 2). This has been further confirmed by an OLS regression. The low value of R^2 indicates the insignificance of correlation between consecutive intervals, which are evidently "memoryless".

Pricing Effectiveness

Gupta (1997) and Lin et al. (1999) have proved that traffic pricing can effectively improve total welfare of network bandwidth service using either first-in-first-out or round-robin bandwidth scheduling method. Current experimental system also has proved this. Figure 3 shows the outcomes from different setups of experiments. Curves *Agent_Pricing*, and *Agent_Non_P* are the welfare rates - total service benefits per second - from experiments using the agent-based traffic generation. The curves indicate that dynamic pricing improves bandwidth service welfare. This is the same result as the one from previous experiments. Similarly, welfare rates, in regard with different levels of traffic arrival rates, obtained from direct experiments using pricing (curve *Human_Pricing*) are relatively higher than the welfare rates from direct experiments without pricing (curve *Human_Non_P*). This strongly suggests the consistency between direct experiments and agent-based experiments. It is noticeable that direct experiments show relatively lower welfare rates than the welfare rates from the same schemes as conducted in agent-based experiment.

Nevertheless, curve *Human_Pricing* is almost parallel to *Agent_Pricing,* and *Human_Non_P* is also almost parallel to *Agent_Non_P*, indicating the compatibility of the outcomes from two types of experiments.

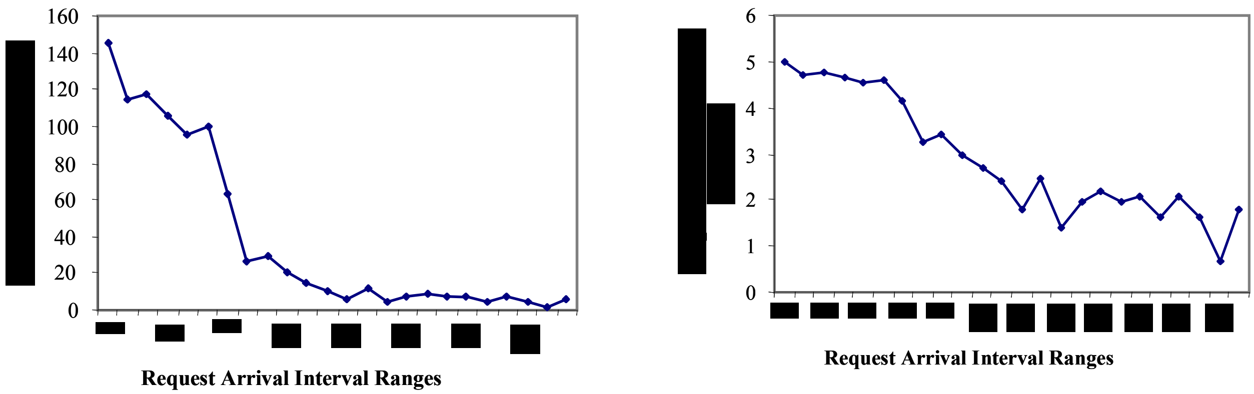

Figure 2. The Histogram of Request Submission Intervals Generated by Human Subjects

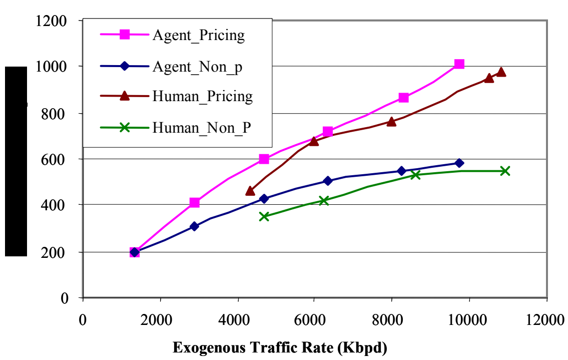

Figure 3. Welfare Rates (Bandwidth: 1544 Kbps)

Subject Performance Comparison

We have mentioned above that the welfare rate observed from direct experiments is lower than that from agent-based experiments. Two possible reasons may cause this: 1) the human errors and occasional irrationality, and 2) the differences of setups between two types of experiments. To investigate the issue, a group of simulations are designed to replay the exogenous traffic patterns recorded from direct experiments. The simulations reproduce the same exogenous traffic generation processes as previously generated from direct experiments. The difference is in that the experimental system with the replaying setup makes optimum submission decisions to maximize the expected user utility for every request. The service welfare rates from these experiments are as good as those from experiments using agent-generated network traffic, and are better than those from direct experiments producing these exogenous traffic patterns (see Table 1). The last column of the table shows that the welfare rate ratio between a direct experiment and the agent-based experiment replaying its traffic pattern, both using traffic pricing scheme, is about 86%. The same ratio for the experiments without using pricing is higher, being 93.3% in a sample case.

Table 1. Welfare Rate Comparison

Schemes	Exog. Traffic Rate (kbps)	Welfare Rate ($/sec) (Direct)	Welfare Rate ($/sec) (Replay)	Welfare Rate Ratio (Direct / Replay)
Dataset 1 (Pricing)	10601	948	1098	86.4%
Dataset 2 (Pricing)	7750	763	893	85.4%
Dataset 3 (Non_pricing)	4695	361	387	93.3%

In checking the size distribution of data flows that are incurred by submitted requests it is impressive that human subjects sometimes tend to make "regrettable" request submission decisions: submitting a request having a positive expected net value but realizing a negative outcome, or dropping a request because of its negative expected net value which would be actually positive if the request were serviced. Each individual subject's performance, in sense of the surplus ratio in two types of experiments, varies from as high as 91.4% to as low as 71.3%, indicating the existence of a subjective factor affecting subjects' performance. In another aspect, as a consequence of the imprecise information available to human subjects and more precise information for computer agents to make decisions, human subjects have a higher average surplus forecasting error with a much higher standard deviation of the error rate, where error rate is the ratio between the error of the estimated user surplus and the average user surplus.

Remarks and Further Research Work

Implementation of the experimental system that allows comparison of performance between human subjects and computer agents provides a good means for us to move the research closer to a real world. It becomes possible to bridge the gap between the economic approach and behavioral approach particularly in the network traffic-pricing area. More experiments are to be conducted to confirm current findings. Issues such as the effect of user interface design on the implementation of network pricing system will be explored. The idea in such an experimental system is now being applied to other research projects.

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