
Issues in Pricing Internet Services

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Motivation

Stagnant telecommunication industry

“We know how to route packets; what we don’t know how to do is route dollars.”

– *David Clark, MIT*

⇒ Need efficient economic mechanisms to increase the profit of Internet service providers

Approach

- Combine economics with network protocol design
 - Economics help identify utilities and strategies of users
 - Protocols are designed to shape and enable the strategies

Goal: Networks mutually beneficial to both users and providers

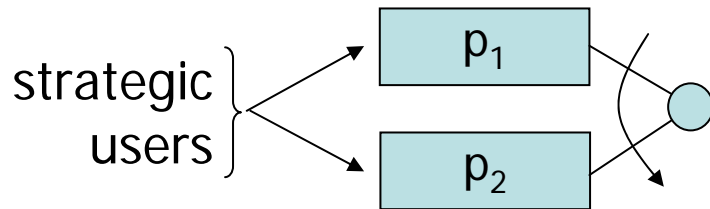
- Essential ingredients

- ✓ More revenues from service differentiation
 - How to price differentiated services?
- Fair distribution of revenue among the providers
 - How should a provider price its share of service?
 - How to promote cooperation instead of competition?

Differentiated Services: Outline

- Service Model
- Motivating Examples
- Equilibria in Many-User Region
- Stable and Efficient Pricing Schemes
- Summary and Future work

Services Model



Users choose the service class that maximizes their net benefit $J_u = f_u(T_i) - p_i$

- Delay T_i
 - no preset targets; determined by users' own choices
 - higher price \Rightarrow smaller delay, if equilibrium exists
- Special issue with Internet services: congestion externality

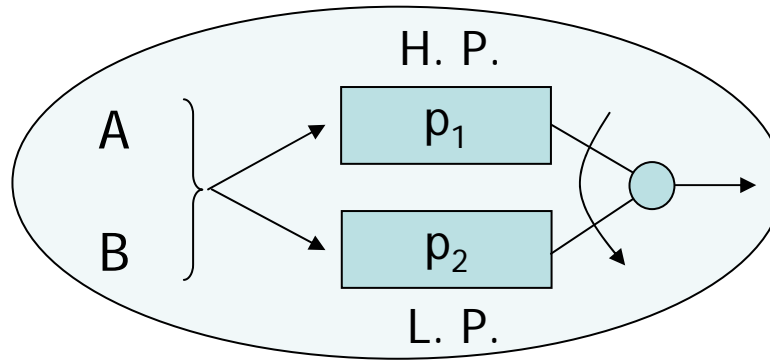
- What kind of equilibrium would happen?
- How to set the prices?

Outcome A. Prisoner's Dilemma

$$f(T_1) = 14$$

$$f(T_0) = 9$$

$$f(T_2) = 5$$



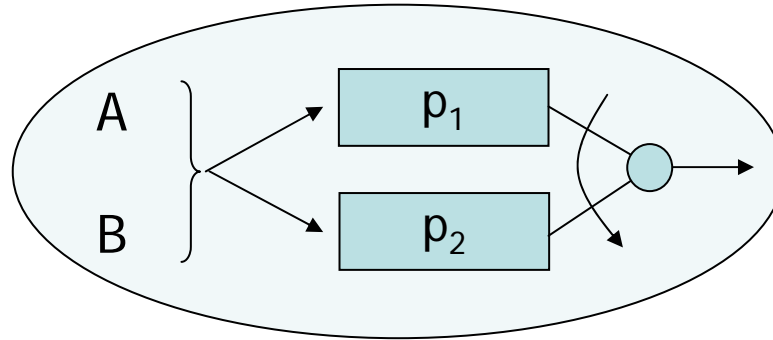
$$p_1 = 4$$

$$p_2 = 1$$

		B	
		H. P.	L. P.
A	H. P.	NE $9-4 = 5$ $9-4 = 5$	$14-4 = 10$ $5-1 = 4$
	L. P.	$5-1 = 4$ $14-4 = 10$	$9-1 = 8$ $9-1 = 8$

Outcome B. No Pure-Strategy Equilibrium

	T_1	T_0	T_2
f_A	13	9	7
f_B	11	9	5



$$p_1 = 4$$

$$p_2 = 1$$

		B	
		H. P.	L. P.
A	H. P.	$9 - 4 = 5$ $9 - 4 = 5$	$13 - 4 = 9$ $5 - 1 = 4$
	L. P.	$7 - 1 = 6$ $11 - 4 = 7$	$9 - 1 = 8$ $9 - 1 = 8$

General Conditions for Two-User Case

		B	
		H. P.	L. P.
A	H. P.	$f_a(T_0) - p_1,$ $f_b(T_0) - p_1$	$f_a(T_1) - p_1,$ $f_b(T_2) - p_2$
	L. P.	$f_a(T_2) - p_2,$ $f_b(T_1) - p_1$	$f_a(T_0) - p_2,$ $f_b(T_0) - p_2$

- If $f_i(T_0) - f_i(T_2) > p_1 - p_2$, both users will choose to use high-price class \Rightarrow Prisoners' Dilemma
- If f_a is convex and f_b is concave, or vice versa, then no pure-strategy equilibrium exists.

Many-User Case

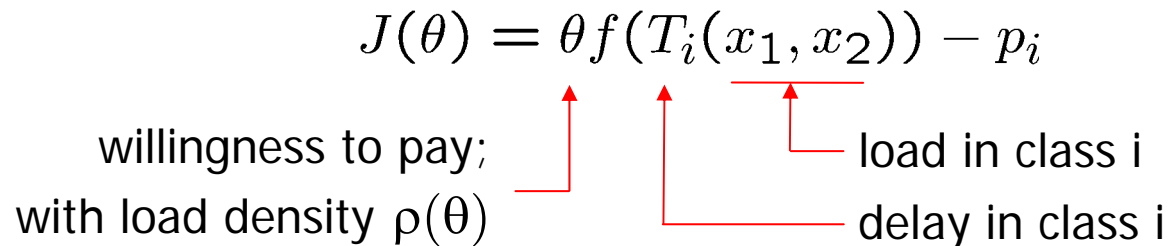
- Model
 - Infinite number of atomic users
 - Fixed load; no flow control, no flow splitting
 - User's payoff function

$$J(\theta) = \theta f(T_i(x_1, x_2)) - p_i$$

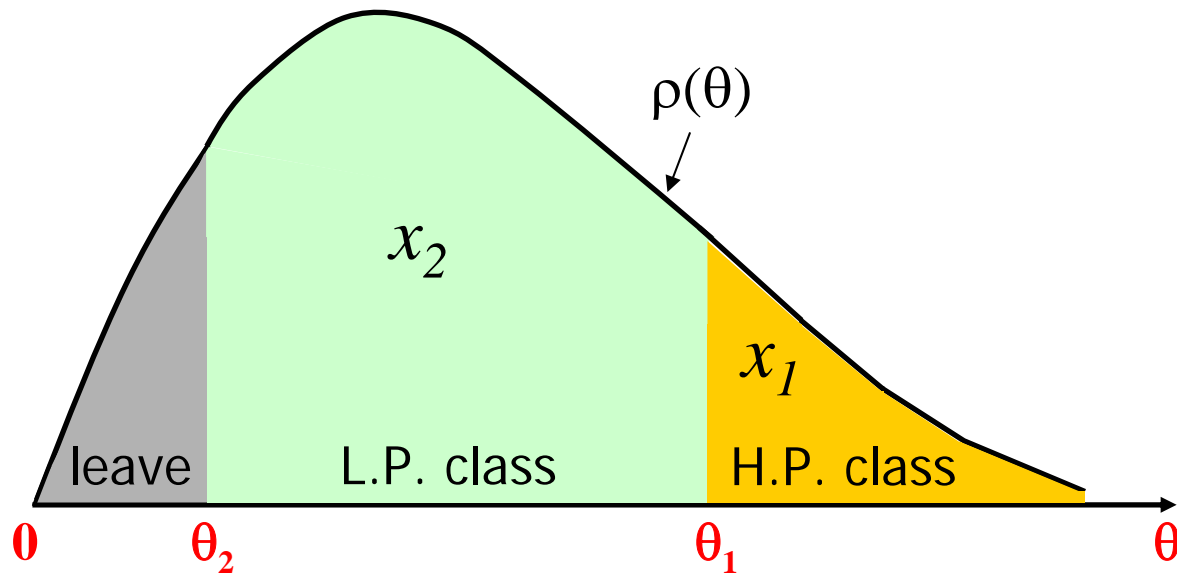
willingness to pay;
with load density $\rho(\theta)$

load in class i

delay in class i



Pure-Strategy Nash Equilibrium



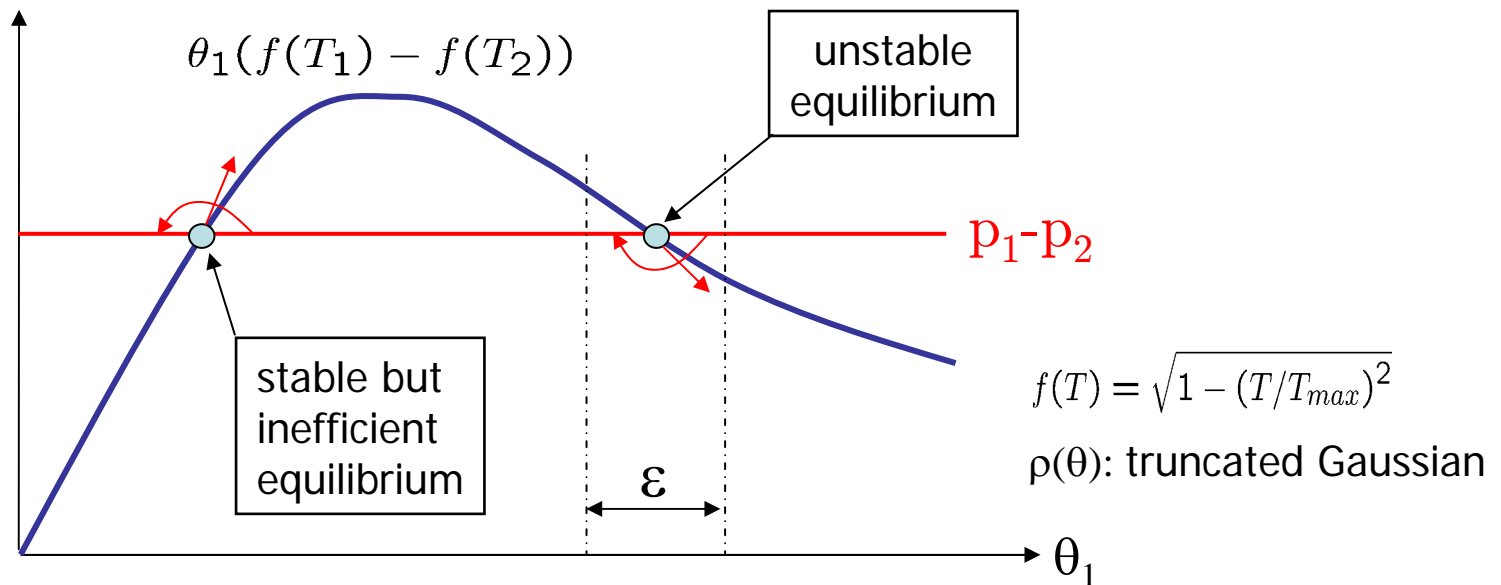
Two marginal uses:

$$\theta_1: \theta_1 f(T_1) - p_1 = \theta_1 f(T_2) - p_2$$

$$\theta_2: \theta_2 f(T_2) = p_2$$

Properties of Equilibria: an example

- Concave utility function; strict-priority scheduling



Unstable if $\Delta = f'(T_1) \left(\frac{\partial T_1}{\partial x_1} - \frac{\partial T_1}{\partial x_2} \right) - f'(T_2) \left(\frac{\partial T_2}{\partial x_1} - \frac{\partial T_2}{\partial x_2} \right) > 0$

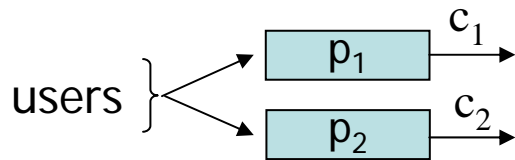
\Rightarrow when congestion externality is significant **between** classes.

Questions

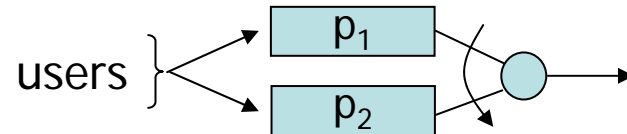
- How to design a stable and efficient system?
- Knobs that one could turn:
 - Scheduling policy
 - Pricing scheme

To Stabilize

- Scheduling policy



Paris-Metro model [Odlyzko]



WFQ/WRR

- Load-based pricing Scheme

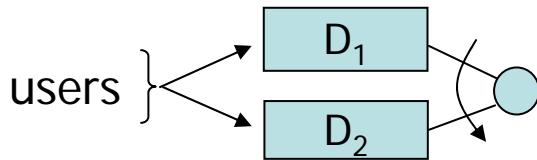
- Let p_1 increase with x_1 while keep p_2 constant
- Choose $p_1(x_1)$ so that $\Delta < 0$ under perturbation
- Resulting equilibrium is stable, if

$$\frac{dp_1}{dx_1} \geq k \sup_{x_2} \left(\underbrace{\frac{\partial T_2}{\partial x_1} + \frac{\partial T_1}{\partial x_2}}_{\text{between class}} - \underbrace{\frac{\partial T_1}{\partial x_1} - \frac{\partial T_2}{\partial x_2}}_{\text{within class}} \right)$$

where k is a bound on $\theta \rho(\theta) |f'(T)|$

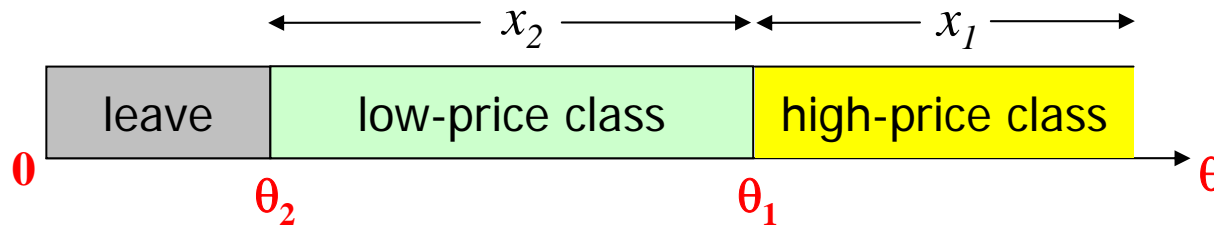
To be efficient

- Delay-based pricing scheme



The same outcome as given by a VCG mechanism, in which users' bids are their θ s

- Equilibrium



two marginal users

$$T_i \left(\underbrace{\int_{\theta_1}^{\infty} \rho(\theta) d\theta}_{x_1}, \underbrace{\int_{\theta_2}^{\theta_1} \rho(\theta) d\theta}_{x_2} \right) = D_i$$

equilibrium prices

$$p_2 = \theta_2 f(T_2)$$

$$p_1 = \theta_1 (f(T_1) - f(T_2)) + p_2$$

Summary and Future Work

- Summary
 - To avoid undesirable equilibria, price differentiation should match quality differentiation
 - Load or delay based pricing schemes can be applied to achieve stable or efficient equilibria
- Future work pertinent to the 100x100 project
 - When access bandwidth is scaled up, do providers still have economic incentives to offer differentiated services?
 - From an economics perspective, is multi-service access + simple high-speed backbone a sensible model?

Other Work on Pricing

- Pricing and revenue sharing in multi-provider network
- Provisioning of SLAs between service providers

Available at

<http://www.eecs.berkeley.edu/~linhai/research>

Thank you!