Market-Based Dynamic Control of Telecommunication Networks

Quanyan Zhu, *IEEE Member*

Advisor: Prof. Peter E. Caines

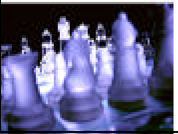
Centre for Intelligent Machines

Industrial Automation Laboratory
Department of Electrical and Computer Engineering
Faculty of Engineering

McGill University
Montreal, Canada

Presentation details on http://www.ece.mcgill.ca/~qzhu4

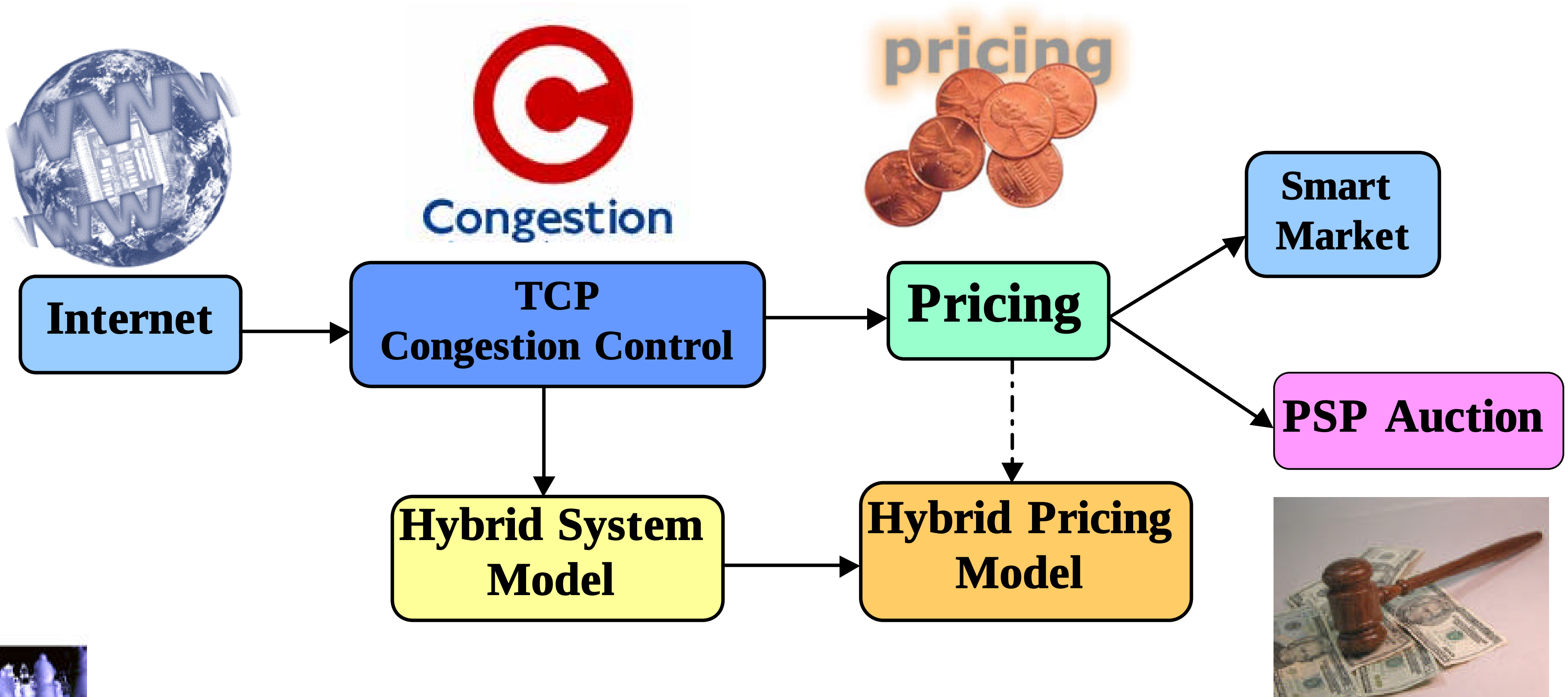
Contact: qzhu4@ieee.org or qzhu4@cim.mcgill.ca

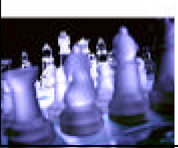


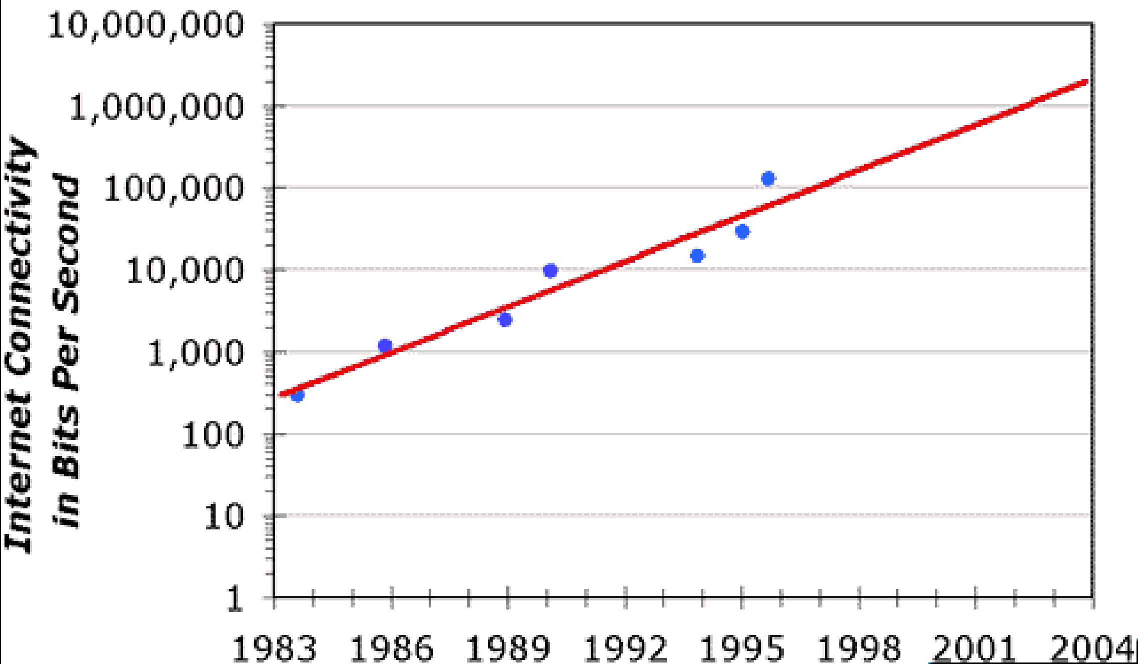
ZENIX Digital Revolution

Outline

- Motivation
- Internet Structure and Congestion Control
- Progressive Second Price (PSP) Auction
- Hybrid System Models





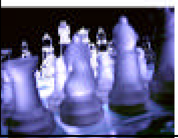


Nielson's Law

(Source: http://www.useit.com)

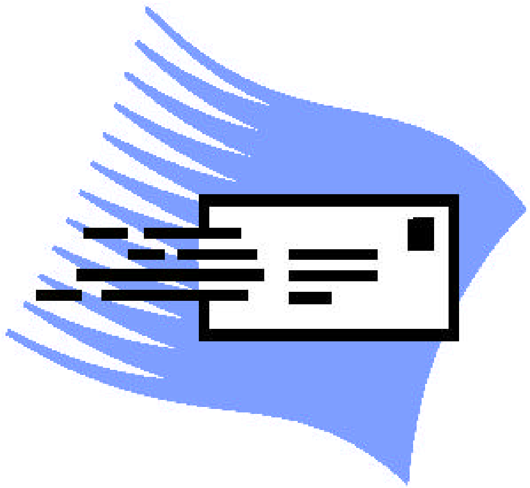
PSINet Backbone

(Source: www.cybergeography.org)



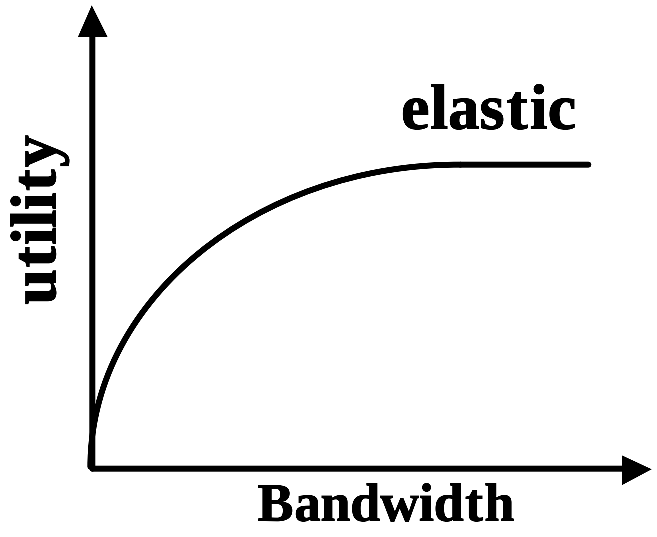
Motivation

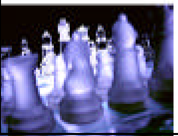
- Current Internet offers
  - **single class** of “best-effort” service.
  - **Flat-rate** pricing
  - **Congestion** is observed
  - Incentive to **overuse** the network
  - Does not allow **service differentiation**



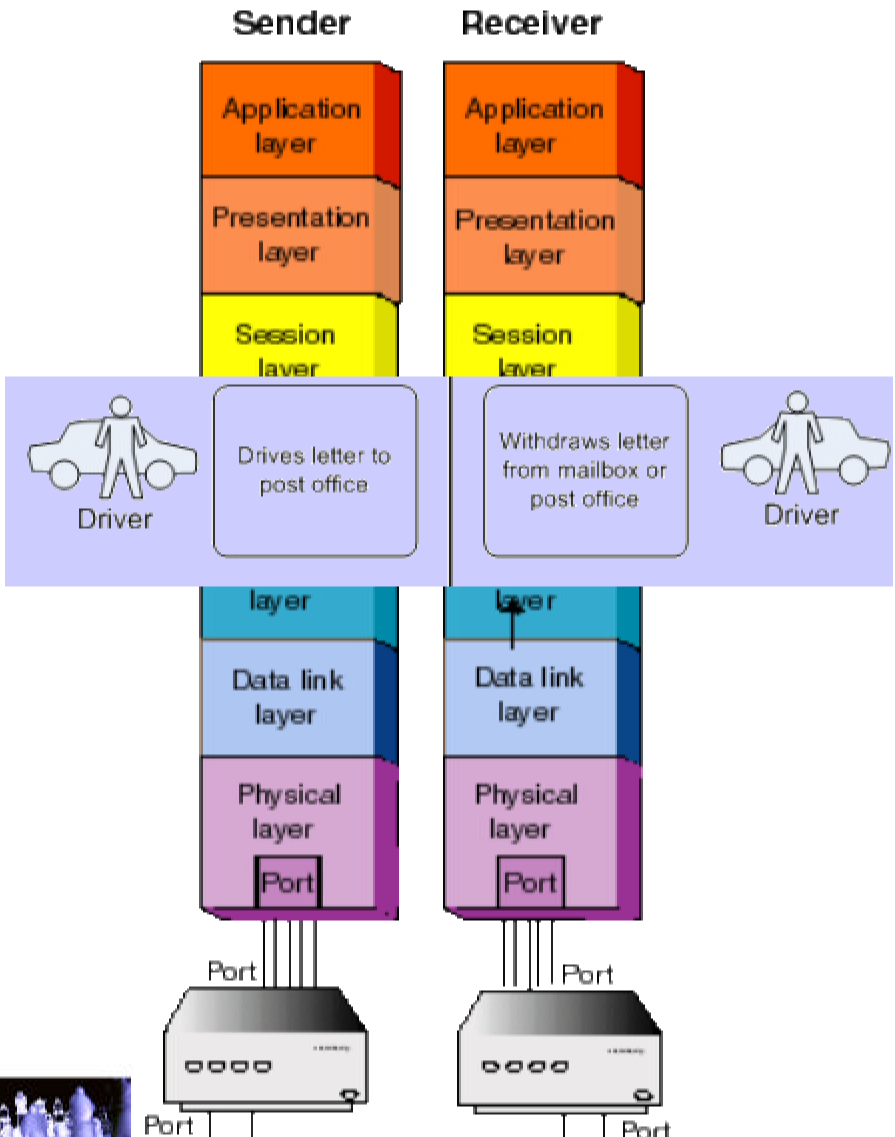
Current Internet

- Current applications are “**elastic**” applications.
  - Rates can be reduced when congestion arises.
  - FTP, SMTP,etc.
- Emerging real-time multimedia applications are “**non-elastic**”
  - High delay in the current Internet → high packet lost rate
  - Poor performances from traditional resources





Internet and Congestion Control

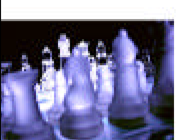


- **UDP**

(User Datagram Protocol)
-**connectionless**
-**unreliable** data transfer

- **TCP**

(Transmission Control Protocol)
-**connection**-oriented
-**reliable** data transfer
-**congestion control** mechanism



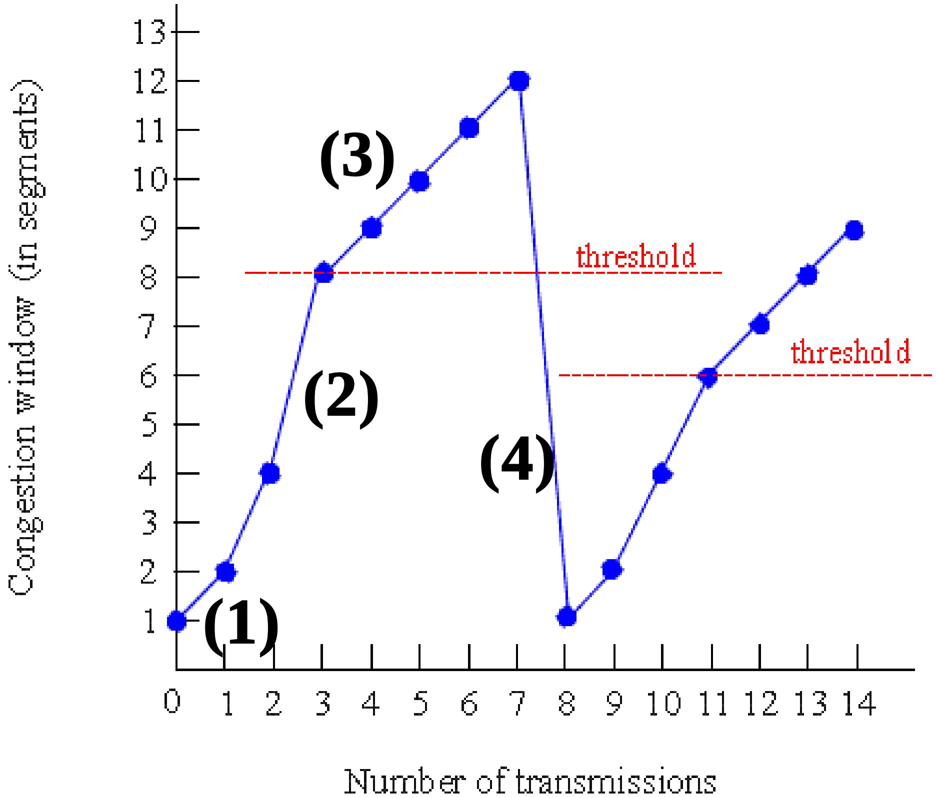
Internet and Congestion Control

(1)Window with a **small** value of window size

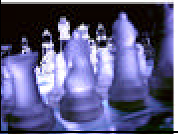
(2)Increase window size **exponentially** (**slow start**)

(3)Window size grows **linearly** (congestion **avoidance**)

(4)Reset to one after time-out



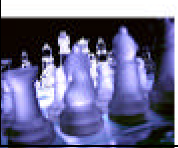
Hybrid System Control



Different Pricing Schemes

- Current Pricing Scheme: **Flat-rate**

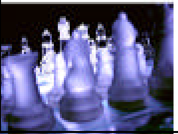
- Different Pricing Schemes
  - **Smart Market,** first scheme with second price auction
  - **Paris Metro Pricing**: networks into sub-networks
  - Pricing based on **transfer rates** and **shadow prices**
  - **Priority Pricing** among different classes.
  - **Auctioning: Progressive Second-Price Auction**



Second-Price Auction

- Auctions is everywhere: internet auctions, spectrum licenses, drilling rights, etc.

- Second Price Auction (Vickery Auction)
  - winner pays the highest of the remaining bids
  - Truth-revealing: everybody tends to bid their true valuation.
  - Equivalent to English Auction



Progressive Second-Price Auction

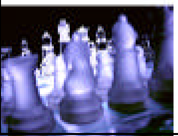
- PSP: **Iterative** Second-Price Auction for **divisible** commodities
- Intended to alleviate the signal burden of packet auctions in **smart market**.

(1) Stability: there exists an e-Nash equilibrium.

(2) Incentive Compatible: there exists a truthful e-best reply

(3) Efficiency: the dynamic game converges efficiently to a truthful e-Nash equilibrium.

> **Under the assumptions of**
>
> **(1)** $q_i(0) = 0$**;**
>
> **(2)** q_i **is differentiable;**
>
> **(3)** $q_i' \geq 0,$ **is non-increasing and continuous;**
>
> **(4)** $\exists g_i > 0, \forall \mathbf{z} \geq 0, q_i'(\mathbf{z}) > 0 \Rightarrow \forall h < \mathbf{z}, q_i'(\mathbf{z}) < q_i'(h) - g_i(\mathbf{z} - h)$
>
> **(concavity assuption up to a point where the curve becomes flat).**
>
> **(5) No budget constraints**



Progressive Second-Price Auction

Sellers calculate (allocation, cost)

$$(a_i^j, c_i^j)_k \quad \forall i \neq j$$

Buyers respond to seller's allocation with new bid (quantity, price)

$$(q_i^j, p_i^j)_{k+1} = (v_i^j, w_i^j)_k \quad \forall i \neq j$$

Buyer's bids (quantity, price)

$$(q_i^j, p_i^j)_k \quad \forall i \neq j$$

Allocation Rule

$$a_i^j(s^j) = \min(q_i, \hat{Q}_i(p_i^j; s_{-i}^j))$$

$$\hat{Q}_i(y; s_{-i}^j) = [q_j^j - \sum_{k \neq i : pk \geq y} q_k^j]^+ \quad \forall y \geq 0, \forall i, j \in I,$$

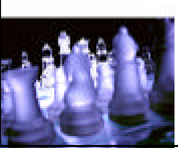
$$c_i^j(s^j) = \sum_{k \neq i} p_k^j [a_k^j(0; s_{-i}^j) - a_k^j(s_i^j; s_{-i}^j)], \forall i, j \in I$$

New Bid Calculation

$$P_i^j(z) = \inf\left\{ y \geq 0 : q_j^j - \sum_{k \neq i : p_k^j > y} q_k^j \geq z \right\}$$

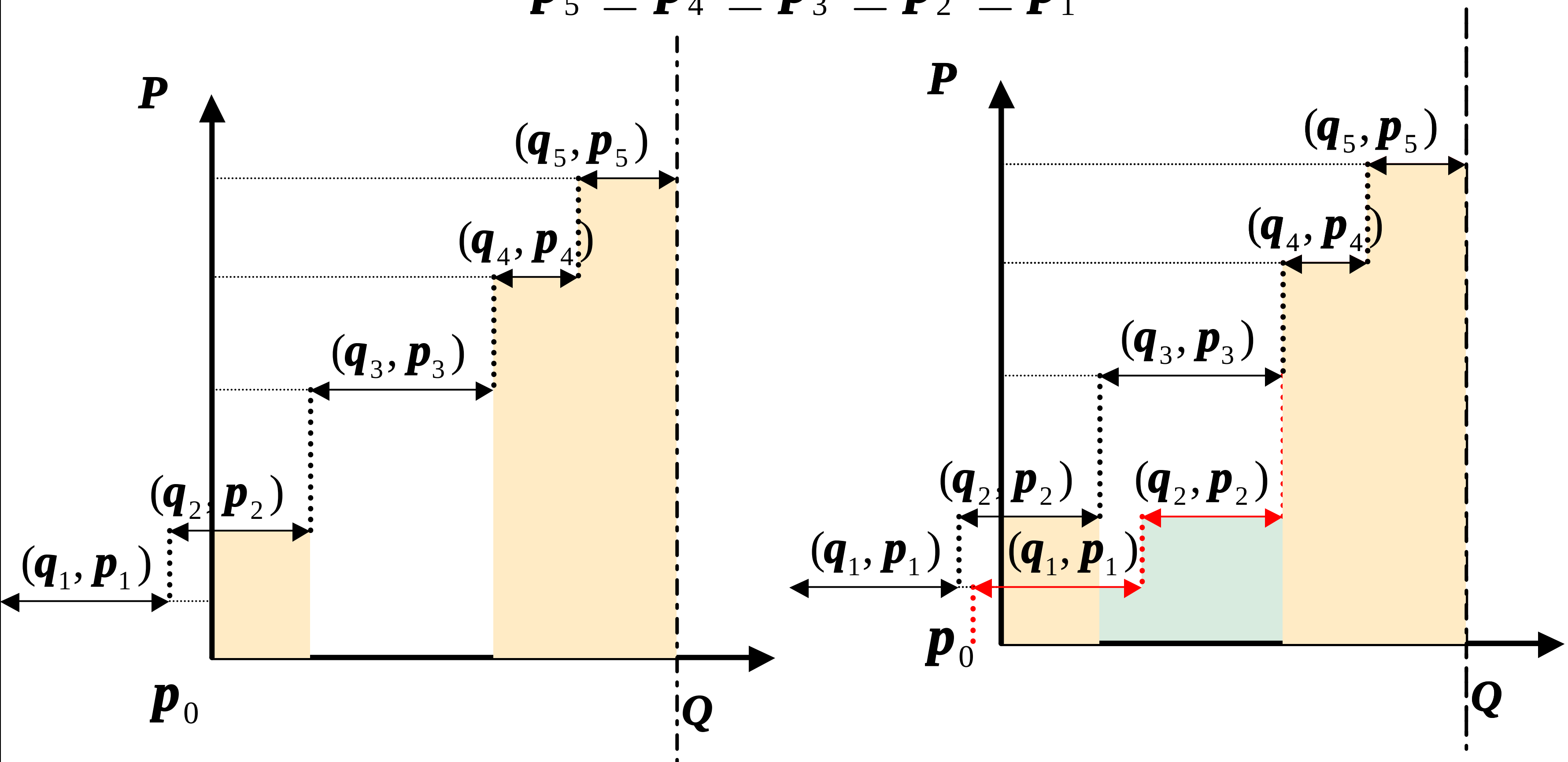
$$v_i^j = \sup\left\{ z \geq 0 : q_i'(z) > P_i^j(z) \text{ and } \int_0^z P_i^j(h)\,dh \leq b_i \right\} - \frac{e}{q_i'(0)}$$

$$w_i^j = q_i'(v_i^j)$$



PSP Example

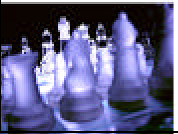
$$p_5 \geq p_4 \geq p_3 \geq p_2 \geq p_1$$



Allocation decision for buyer 3:

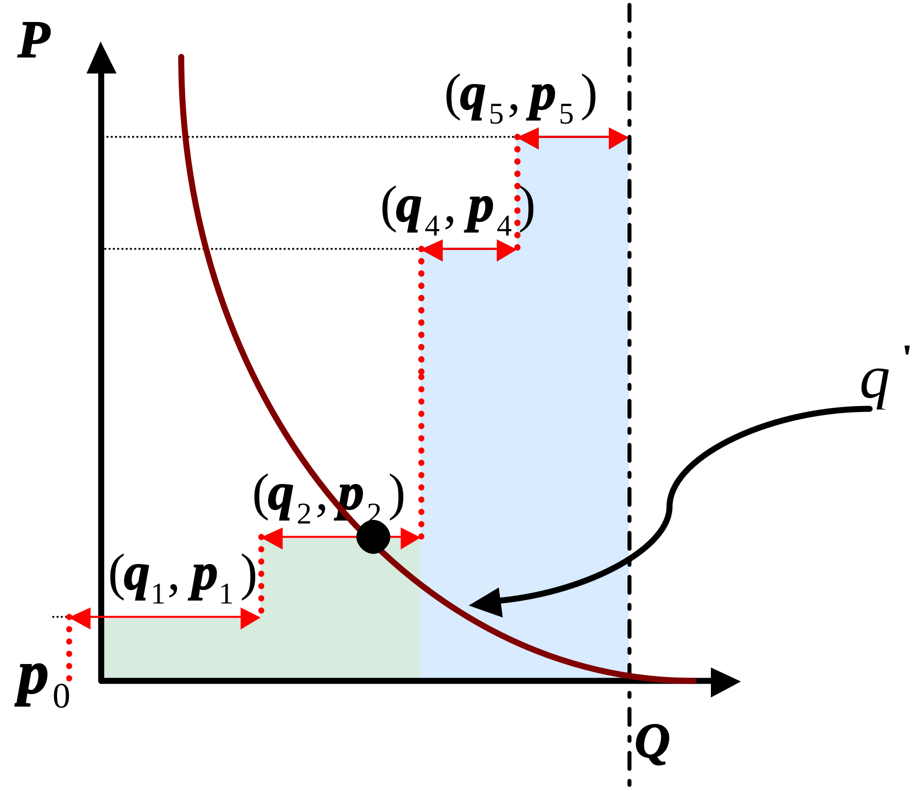
a_3: q_3

c_3: **difference under the area**



PSP Example

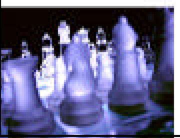
$$p_5 \geq p_4 \geq p_3 \geq p_2 \geq p_1, p_0 = 0, e = 0$$



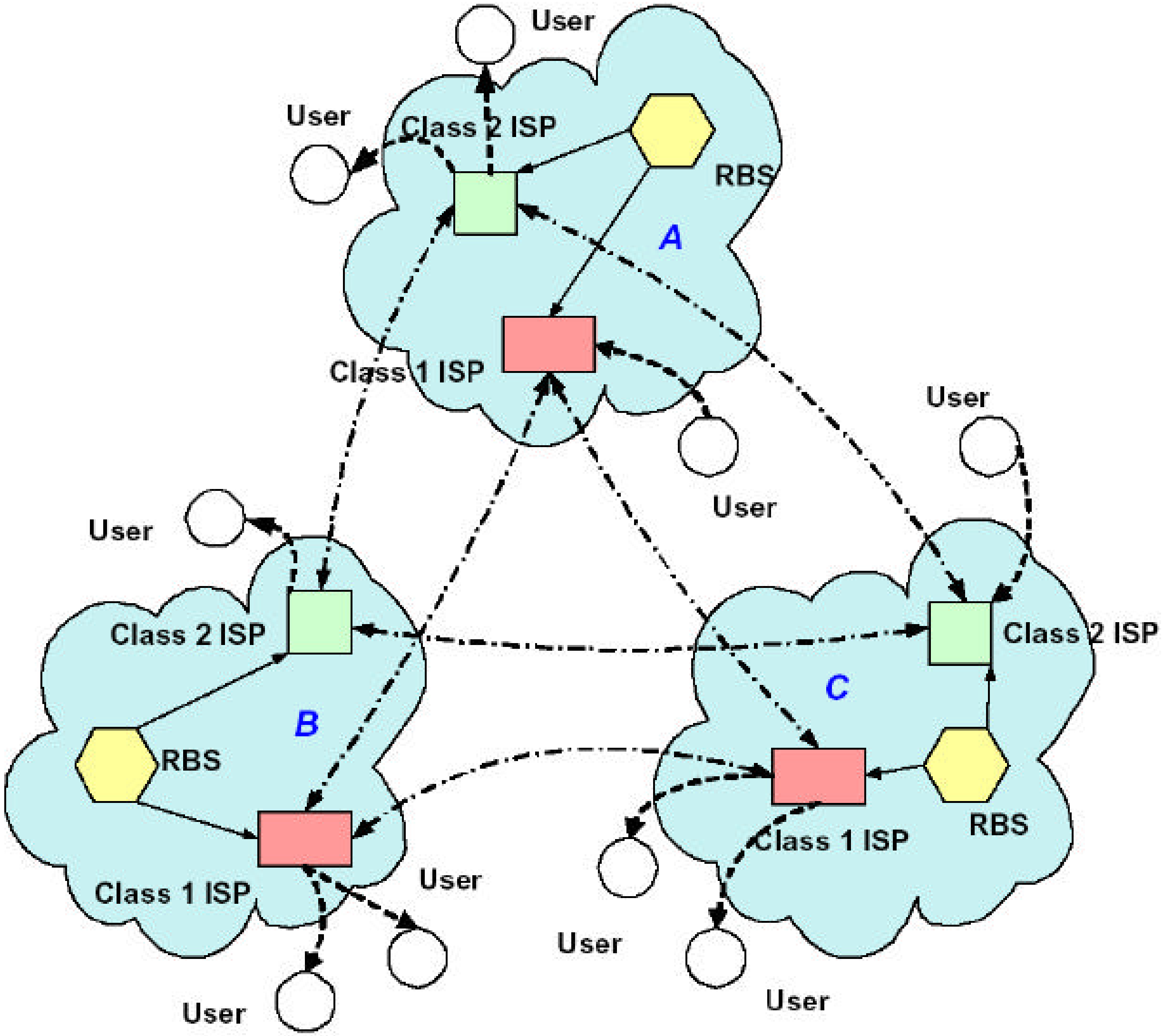
Second-round bidding:

$v_3 : q_2$

$w_3 : p_2$



PSP Model used for Networks



Hybrid System Models of Computer Networks

Dynamical systems with interacting continuous dynamics and discrete-event dynamics

Cf. Packet-level model simulation

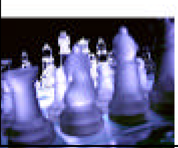
(1) Improves the computation requirement for large scale of simulations

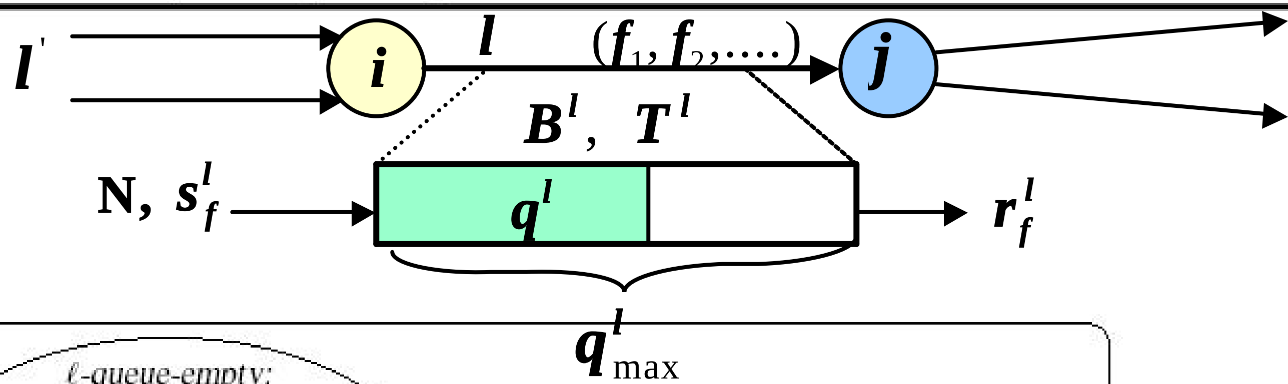
(2) Alleviate the difficulty in understanding network parameters affecting overall performance

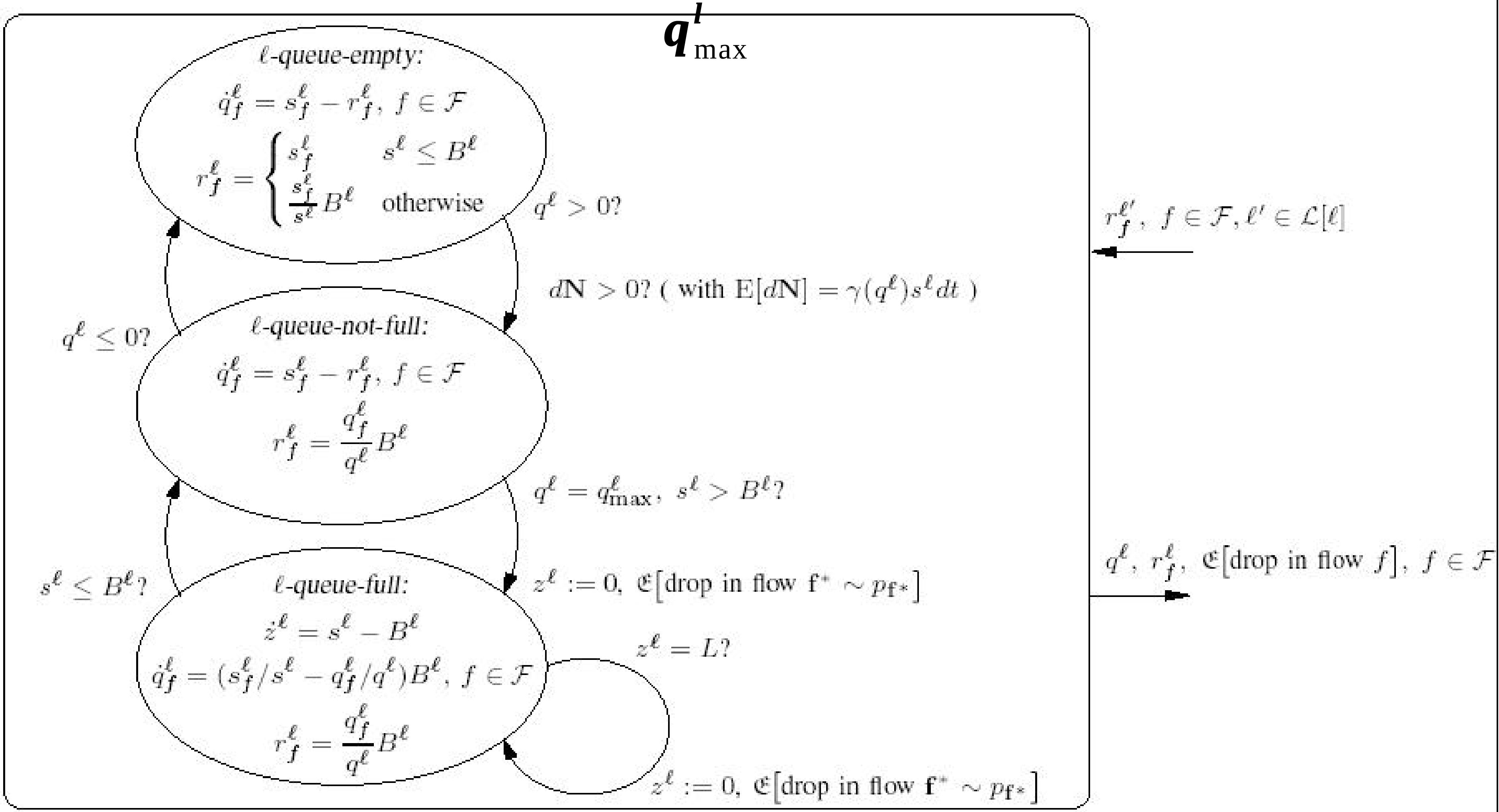
Cf. Fluid Model

(1) Captures the transient dynamics

(2) Provides flexibility in modeling

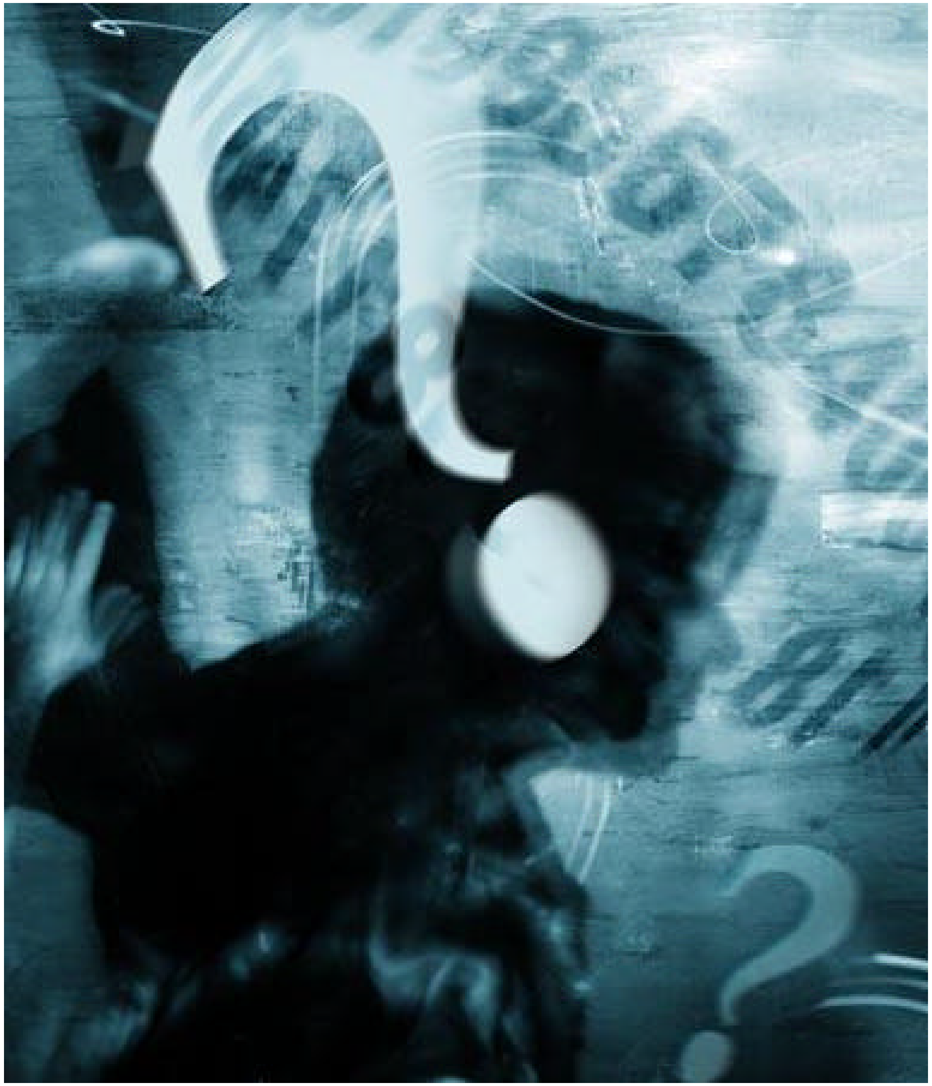



l'
i
l
$(f_1, f_2, \ldots)$
j
$B^l,\ T^l$
$\mathbf{N},\ s_f^l$
q^l
r_f^l
$q_{\max}^l$


ℓ-queue-empty:
$\dot{q}_f^\ell = s_f^\ell - r_f^\ell,\ f \in \mathcal{F}$
$r_f^\ell = \begin{cases} s_f^\ell & s^\ell \le B^\ell \\ \frac{s_f^\ell}{s^\ell} B^\ell & \text{otherwise} \end{cases}$
$q^\ell > 0?$
$d\mathbf{N} > 0?$ (with $\mathrm{E}[d\mathbf{N}] = \gamma(q^\ell) s^\ell dt$)
$q^\ell \le 0?$
ℓ-queue-not-full:
$\dot{q}_f^\ell = s_f^\ell - r_f^\ell,\ f \in \mathcal{F}$
$r_f^\ell = \frac{q_f^\ell}{q^\ell} B^\ell$
$q^\ell = q_{\max}^\ell,\ s^\ell > B^\ell?$
$z^\ell := 0,\ \mathfrak{E}[\text{drop in flow } \mathrm{f}^* \sim p_{\mathrm{f}^*}]$
$s^\ell \le B^\ell?$
ℓ-queue-full:
$z^\ell = s^\ell - B^\ell$
$\dot{q}_f^\ell = (s_f^\ell / s^\ell - q_f^\ell / q^\ell) B^\ell,\ f \in \mathcal{F}$
$r_f^\ell = \frac{q_f^\ell}{q^\ell} B^\ell$
$z^\ell = L?$
$z^\ell := 0,\ \mathfrak{E}[\text{drop in flow } \mathbf{f}^* \sim p_{\mathbf{f}^*}]$
$r_f^{\ell'},\ f \in \mathcal{F}, \ell' \in \mathcal{L}[\ell]$
$q^\ell,\ r_f^\ell,\ \mathfrak{E}[\text{drop in flow } f],\ f \in \mathcal{F}$

Future Subsequent Work

- Hybrid Model of TCP
  - **Modification** on the previous model by adding modes such as time-out, congestion avoidance, and congestion delay.
- Pricing Model from a System Perspective
  - Incorporate **PSP** into the model
  - **Simulation** on simple network topologies
- Improvements of PSP
  - Cases in which **equal bids** are possible
  - **Asynchronous** bidding
  - **Reserve prices**
  - **Admission prices**
  - **Demand functions**



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(2) N. Semret, R.Liao, A. T.Campbell, A. A.Lazar, “Pricing, Provisioning and Peering: Dynamic Markets for Differentiated Internet Services and Implications for Network Interconnections”, IEEE Journal on Selected Areas in Communications, Vol. 18, No. 12, Dec. 2000

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