Pricing Internet Access

-- How To Engineer Your Monthly Bill

Mung Chiang, Princeton University

South California Symposium On Network Economics, November 11, 2010

Some 2010 (WSJ) Headlines

1 OCTOBER 19, 2010, 1:09 P.M. ET

3rd UPDATE:Verizon Wireless To Unveil Tiered Data Plan Oct 28

1 TECHNOLOGY
2 OCTOBER 15, 2010

FCC Unveils Billing Rules

1 E 3, 2010

AT&T's Wireless Pricing Shift Will Test Behavior

AT&T Sees Hope on Web Rules

Executive Sees Positive Step in Google-Verizon Proposal on Broadband Regulation

1 TECHNOLOGY
2 MAY 5, 2010

New U.S. Push to Regulate Internet Access

1 TECHNOLOGY
2 JUNE 2, 2010

AT&T Dials Up Limits on Web Data

Broadband Plan Faces Hurdles

What Your New Bill May Look Like

Quick Bill Summary

Sep 17 – Oct 16

Previous Balance *(see back for details)*	$225.69
Payment – Thank You	–$225.69
Balance Forward	**$.00**
Monthly Access Charges	$153.96
Usage Charges	
Voice	$.00
Messaging	$10.40
Data	$21.97
Verizon Wireless' Surcharges and Other Charges & Credits	$5.70
Taxes, Governmental Surcharges & Fees	$11.50
Total Current Charges	**$203.53**
Total Charges Due by November 11, 2010	**$203.53**

Charges

Monthly Access Charges

AC Family SharePlan 1400 10/17 – 11/16	80.00
~~15% Access Discount 10/17 – 11/16~~ paid in part by Apple	–12.00
BlackBerry Unlimited BBA 10/17 – 11/16	44.99
20% – Feature Discount 10/17 – 11/16	–9.00
	$103.99

Time of usage discount $69.88

Usage Charges

Voice		**Allowance**	**Used**	**Billable**	**Cost**
SharePlan	*minutes*	1400 (shared)	203	--	--
Mobile to Mobile	*minutes*	unlimited	162	--	--

Guaranteed express delivery

Data		**Allowance**	**Used**	**Billable**	**Cost**
~~Premium Messaging~~	*messages*	--	1	1	9.99
Other Charges	*minutes*	--	1	1	1.99
Kilobyte Usage	*kilobytes*	unlimited	2608		
Total Data					$11.98
Total Usage Charges					**$22.18**

Usage price $50.99

Verizon Wireless' Surcharges

Fed Universal Service Charge	.59
Regulatory Charge	.13
Administrative Charge	.83
	$1.55

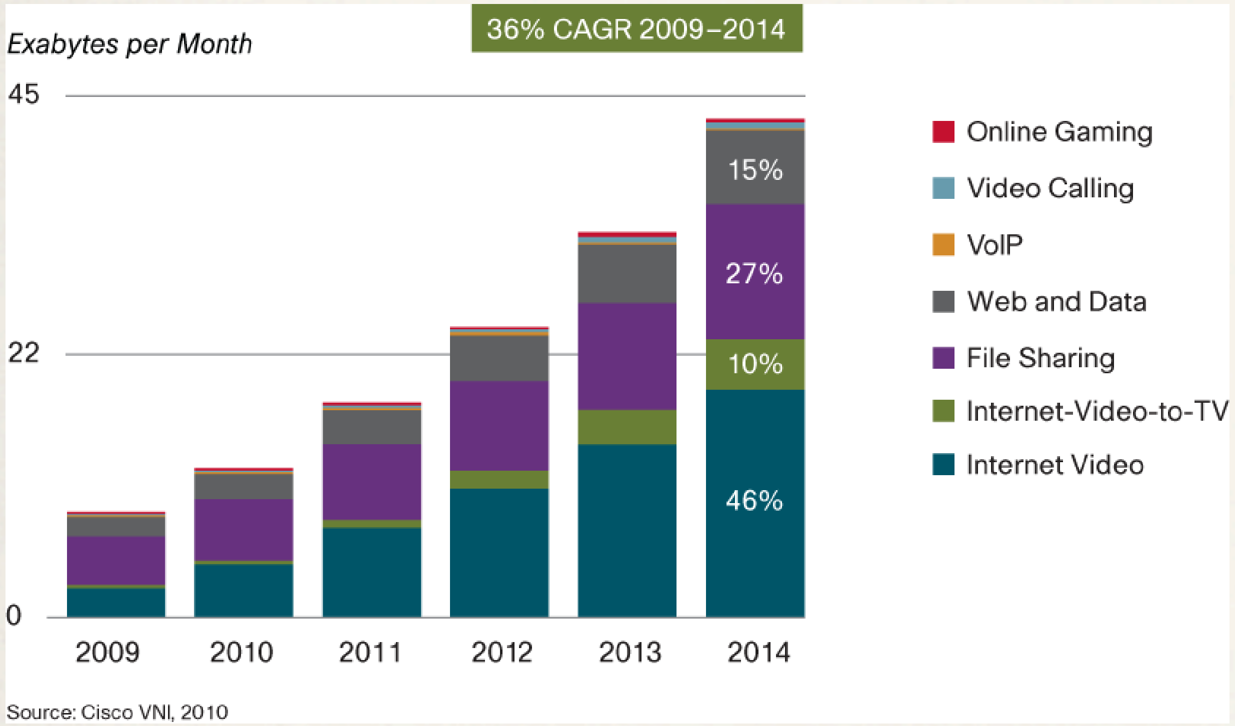
Some of the 45 types of taxes I pay

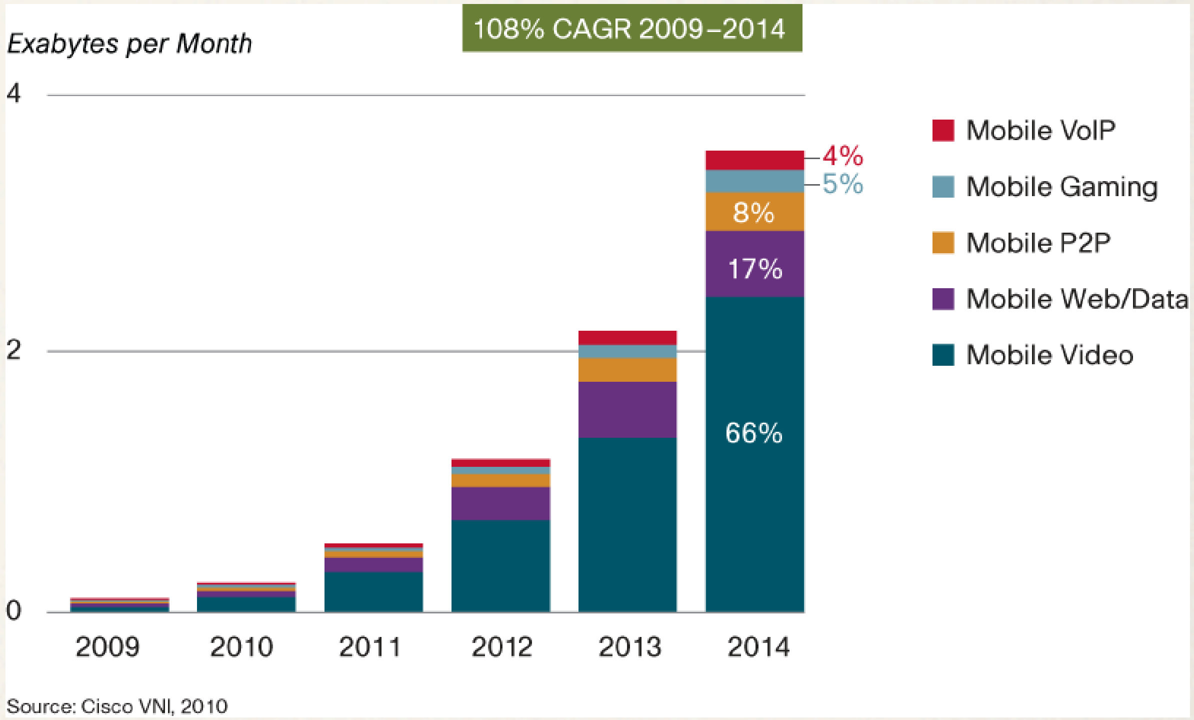
Taxes, Governmental Surcharges and Fees

NJ 911 System/Emerg. Resp. Fee	.90
NJ State Sales Tax	2.35
	$3.25

Why

- Pricing can lift the pressure valve off the Internet traffic explosion





Issues at Stake

1. Four Questions of Pricing

- What to Charge?
- Whom to Charge?
- How much to Charge?
- How to Charge?

2. Universal Coverage

- FCC National Broadband Plan
  - How to improve reach and speed of US broadband access?
- Who's going to pay the $350B bill?
  - Consumer?
  - Taxpayer?
  - Others?

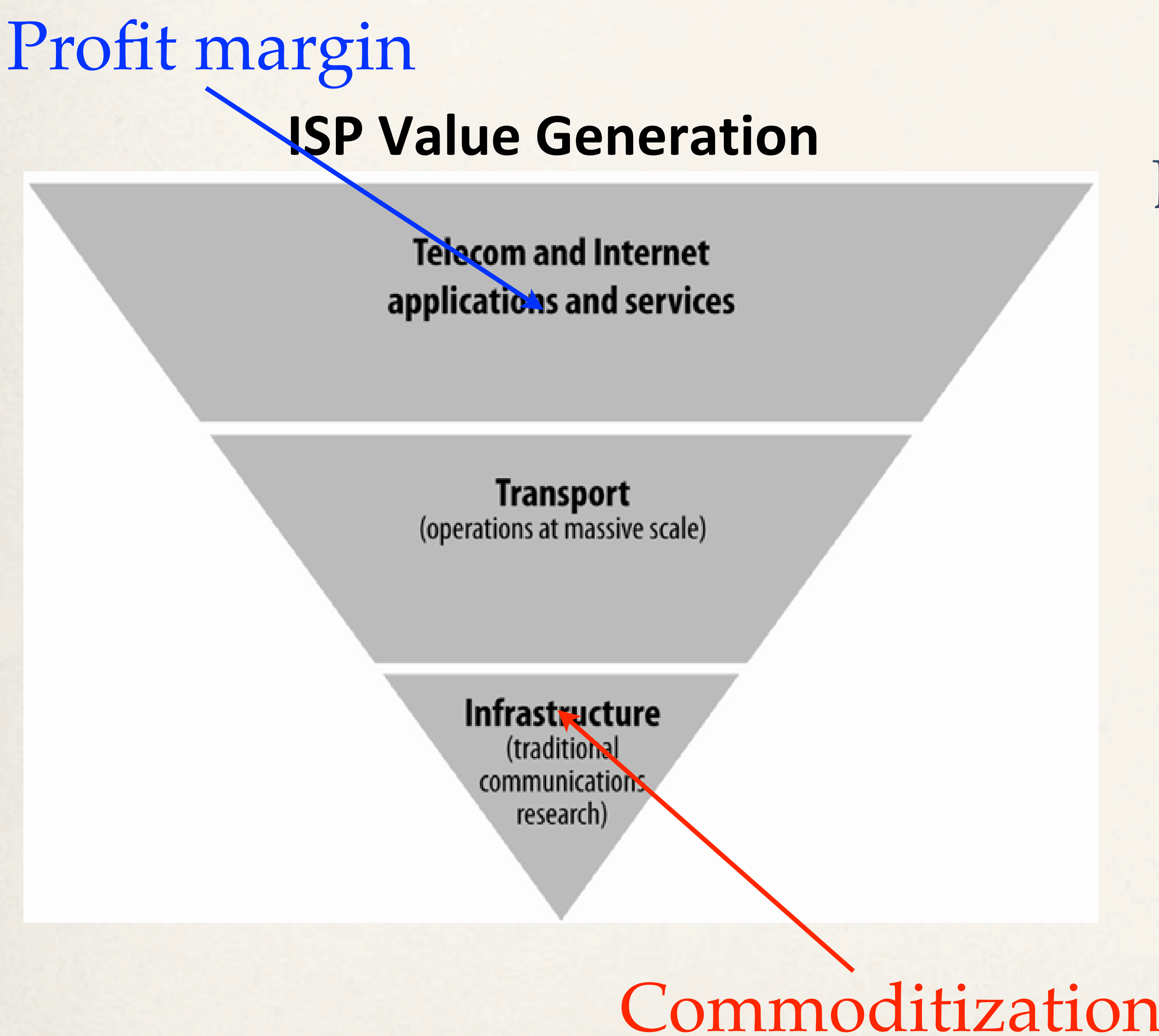
3. Network Neutrality

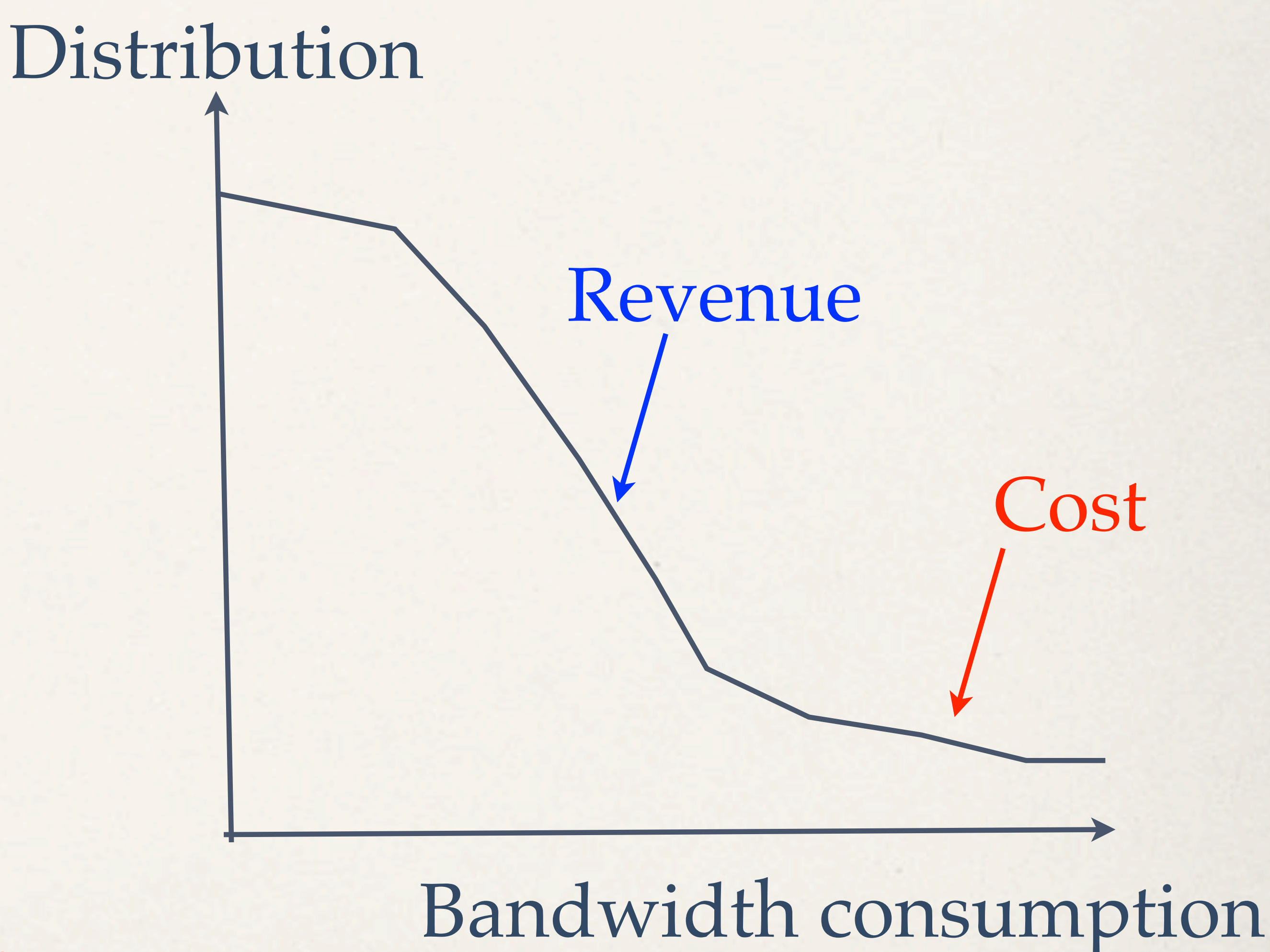
- Different Definitions:
  - Access/choice ✓
  - Competition/No monopoly ✓
  - Equality/No discrimination ✗
- Tough Issues:
  - Efficiency-fairness tradeoffs in parties with conflicting interests
  - Incentives for innovation and consumer experience

Colors of Neutrality

- Red: vertical integration and service limitation ✗
- Orange: protocol/user-ID based discrimination ✓
- Yellow: usage-based pricing ✓
- Green: traffic management and QoS provisioning ✓
- Roles of government?
  - Enable viable competition, or ✓
  - Regulatory micro-management? ✗

4. ISPs Two Problems





New Business Models for ISPs

- Avoid commoditization
- Offer value-added services beyond connectivity service
- Bridge content-pipe divide
  - Need a new interface between ISP and content/app providers
- Innovate pricing
  - Pricing as Network Management (if timescales match)

Nature of This Talk

- Not on specific model/analytic/numerical results
- Not an exhaustive overview of pricing literature
- Not on non-access Internet pricing or general network economics

- A biased path traversing vertices of the problem space
  - And samples challenges facing the research community

Two-Way Interactions: Subject

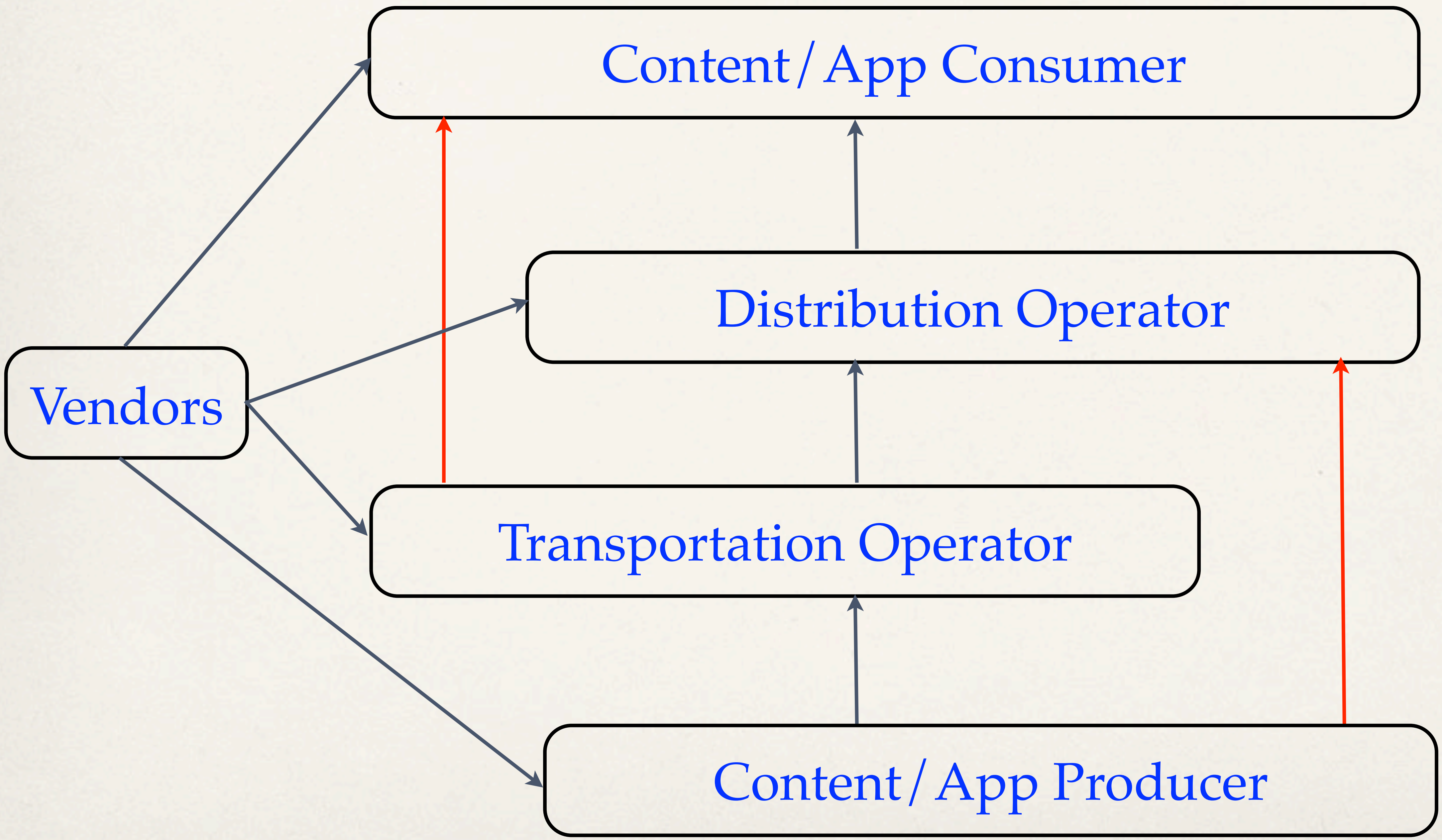
- Pricing changes technology
  - Video ads in support of cheap app/content
- Technology changes pricing
  - Heterogeneous wireless platforms

Two Way Interactions: Method

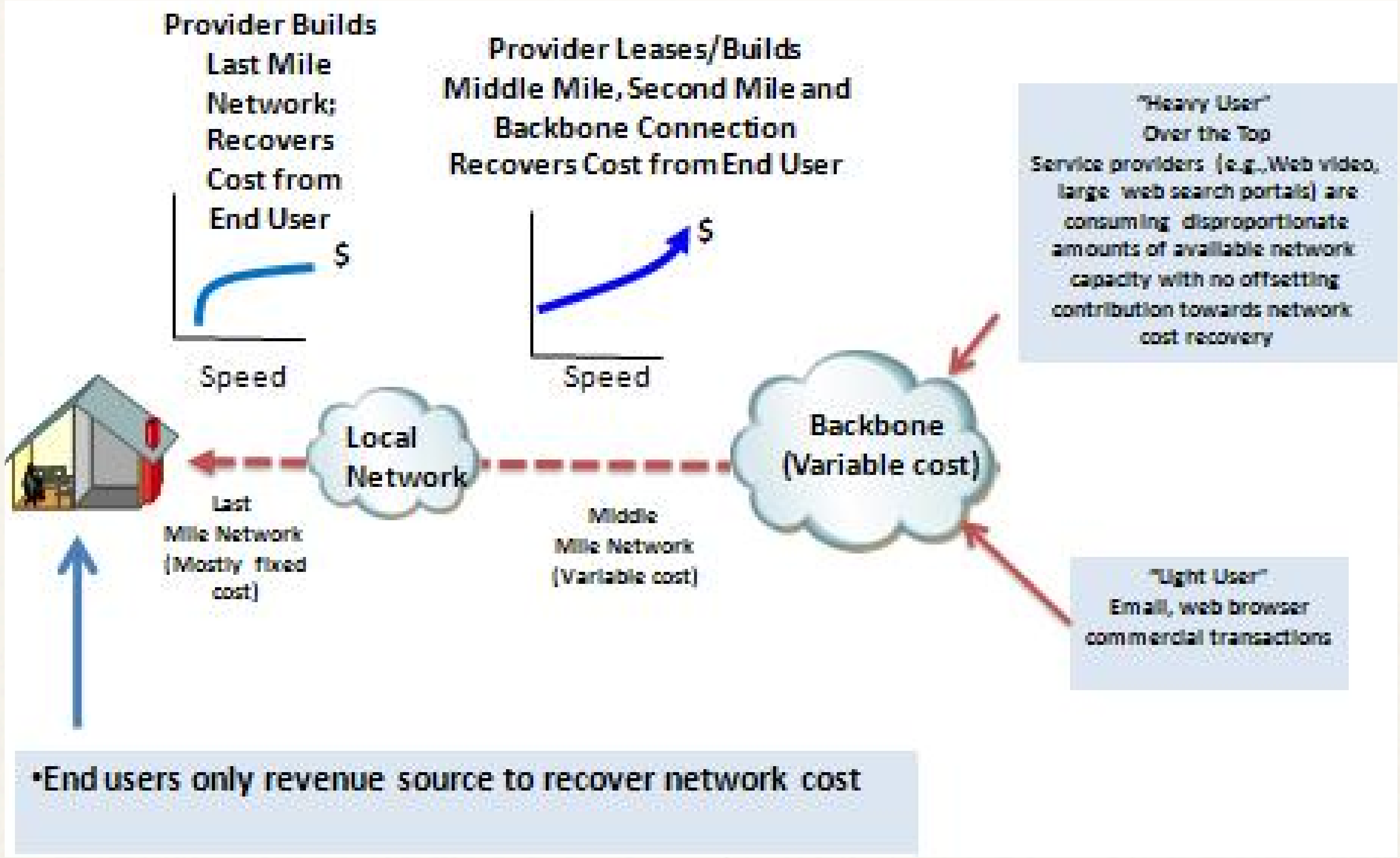
- Engineering research benefits from economics research
  - 2-sided, utility model, game, auction, etc.
- Economics research benefits from engineering research
  - Dynamically varying interaction model

Sample Scenarios

5-Party Interactions

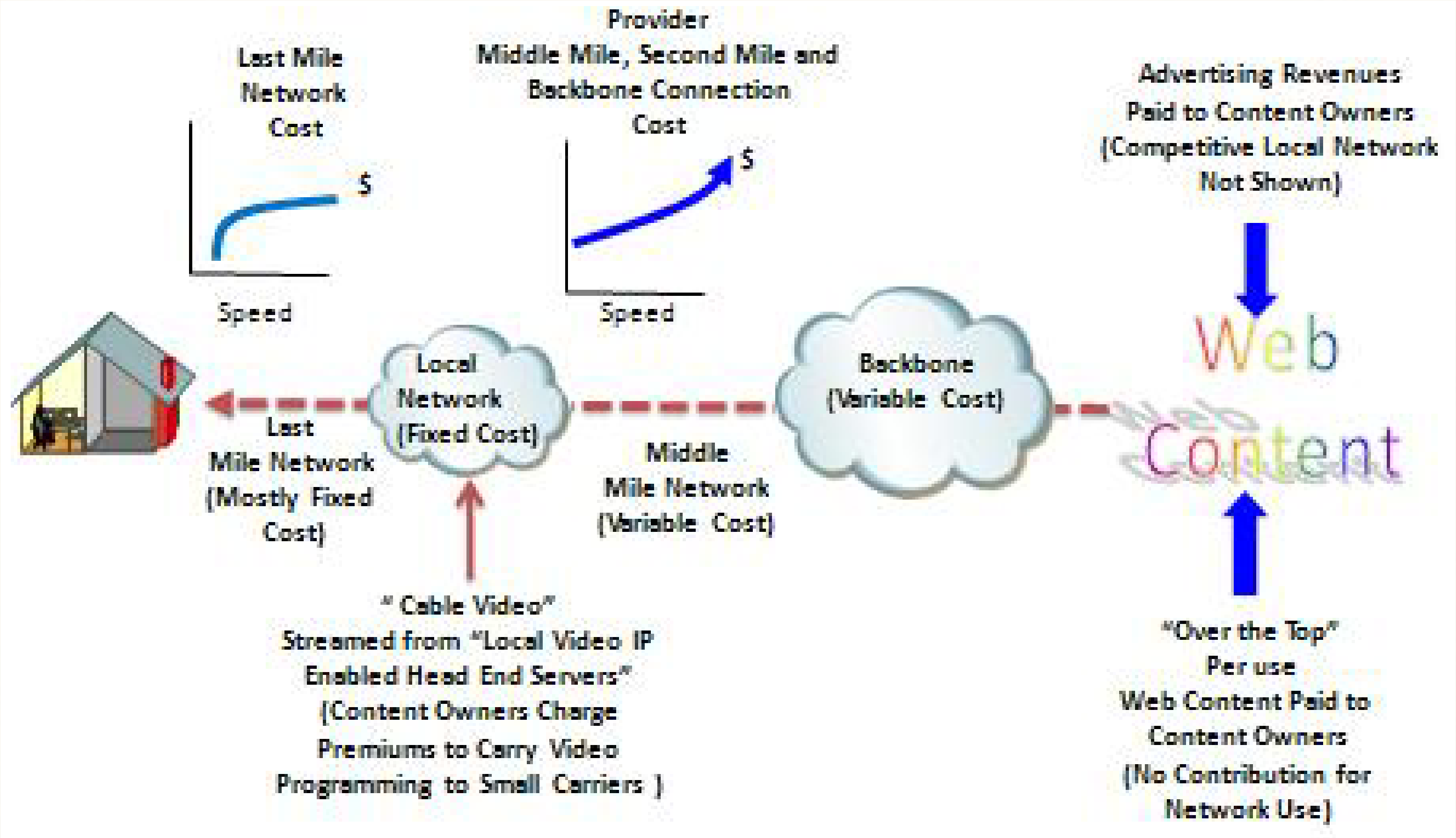


Basic Benchmark



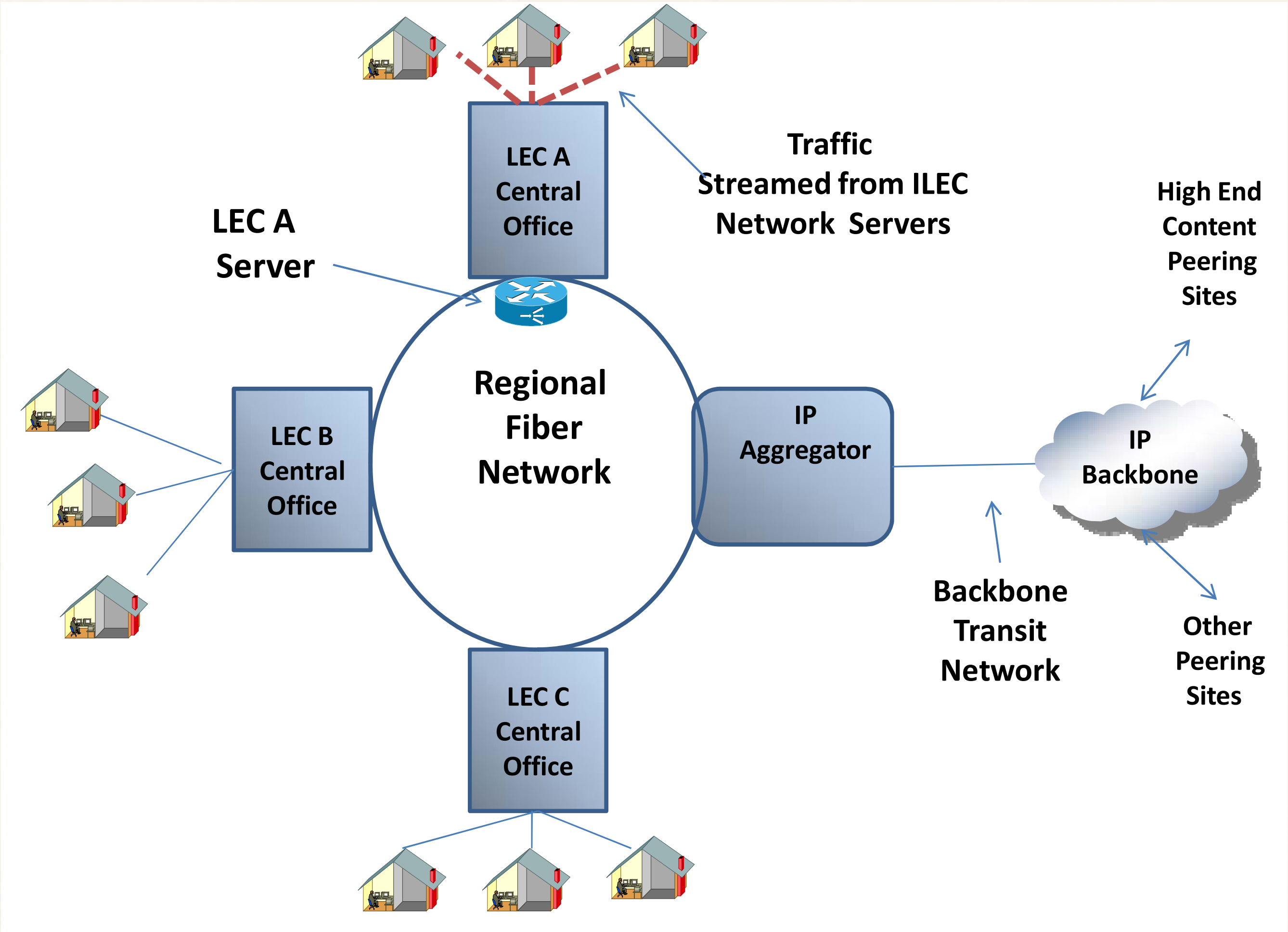
Cost recovery via median-user, 1-sided pricing is challenging

Cost Recovery



The Potential of 2-sided pricing

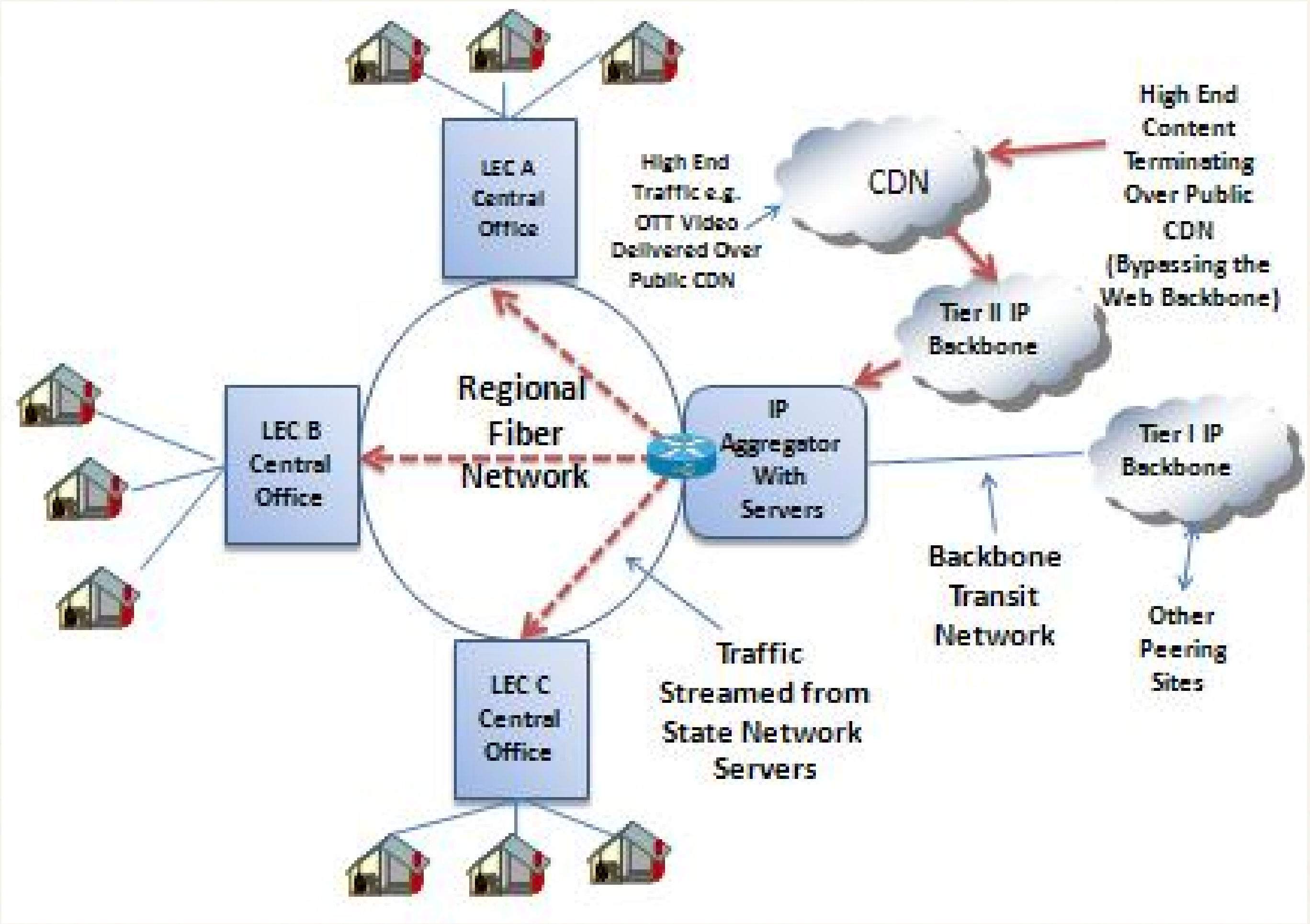
Adding Server by ISP



Localization of traffic

Impact on middle mile cost recovery

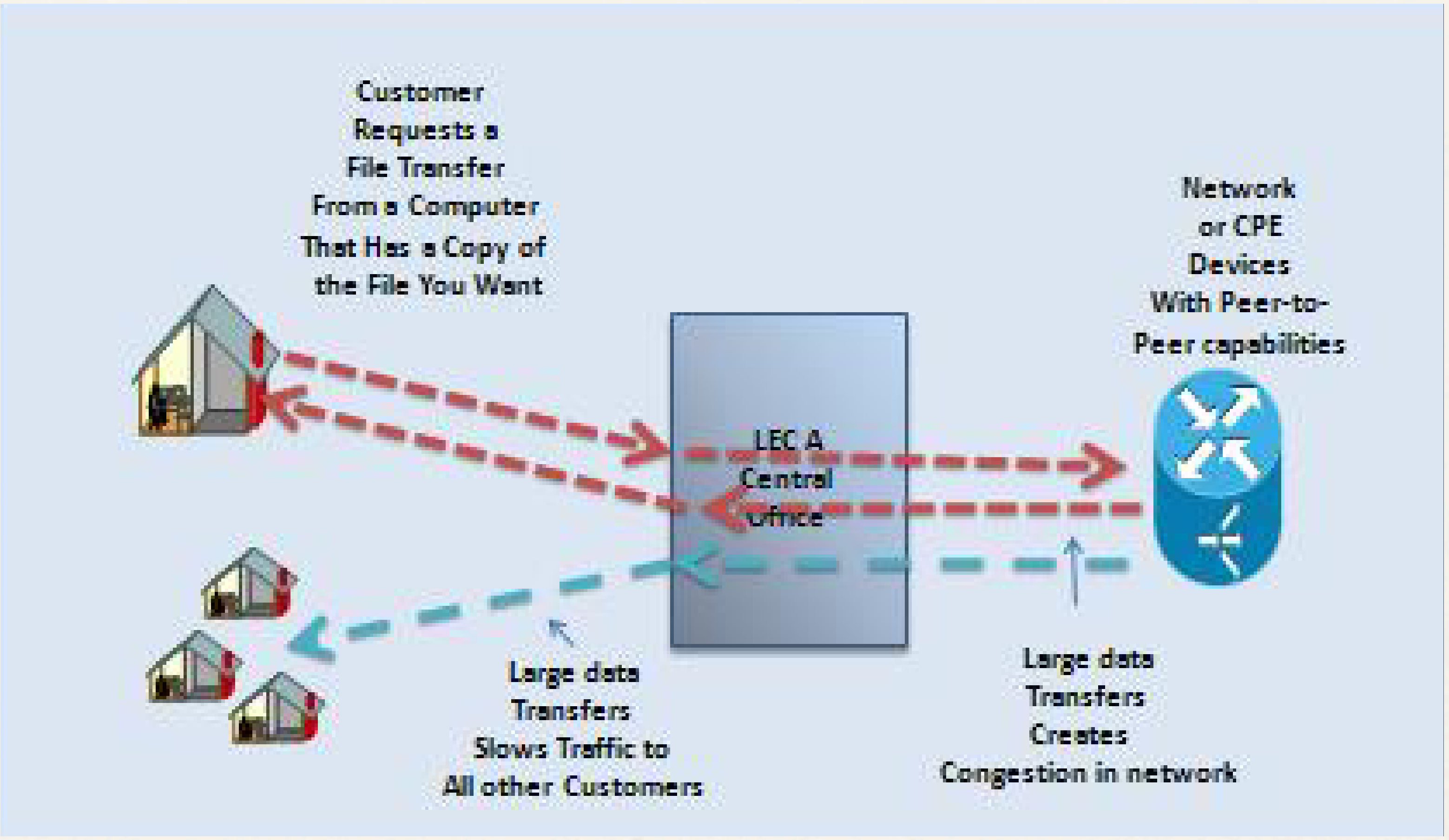
Distribution by CDN



CDN contract and net cost reduction

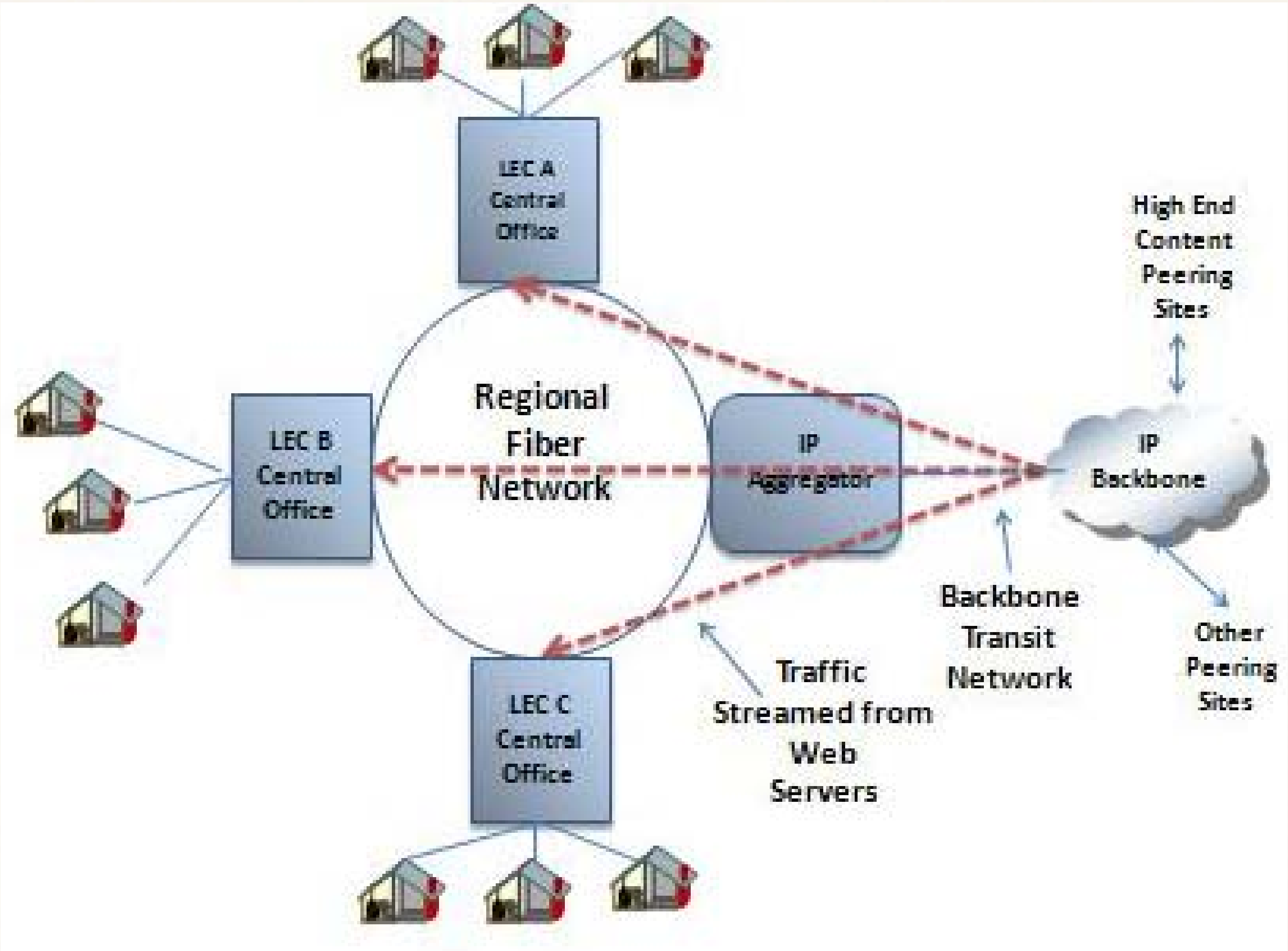
How to charge between CDN and ISP

Distribution by P2P



P2P dynamically changes traffic distribution

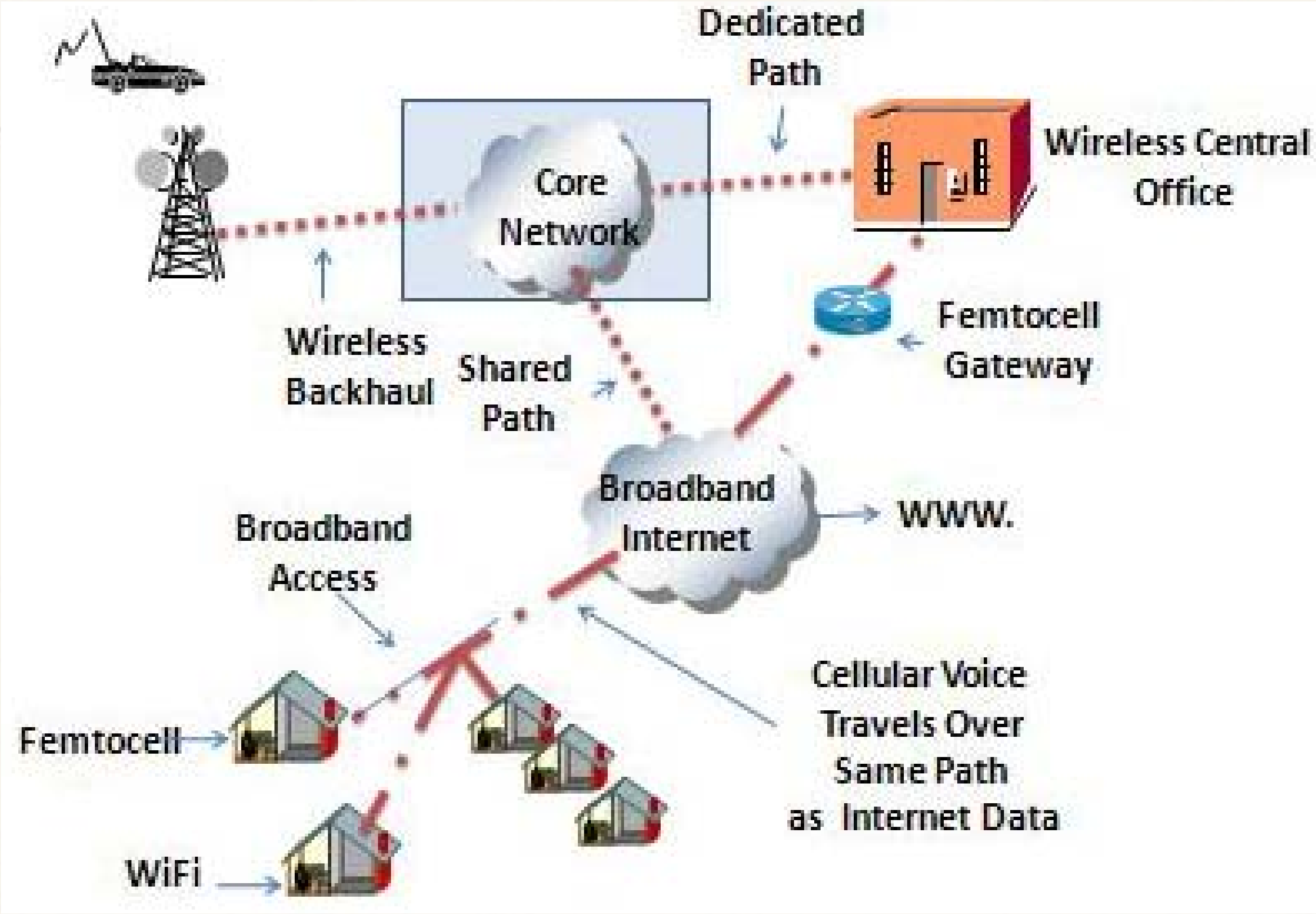
Video Multicasting



The challenges of scaling up multicast streaming

Regulatory issue of bundling

Wireless



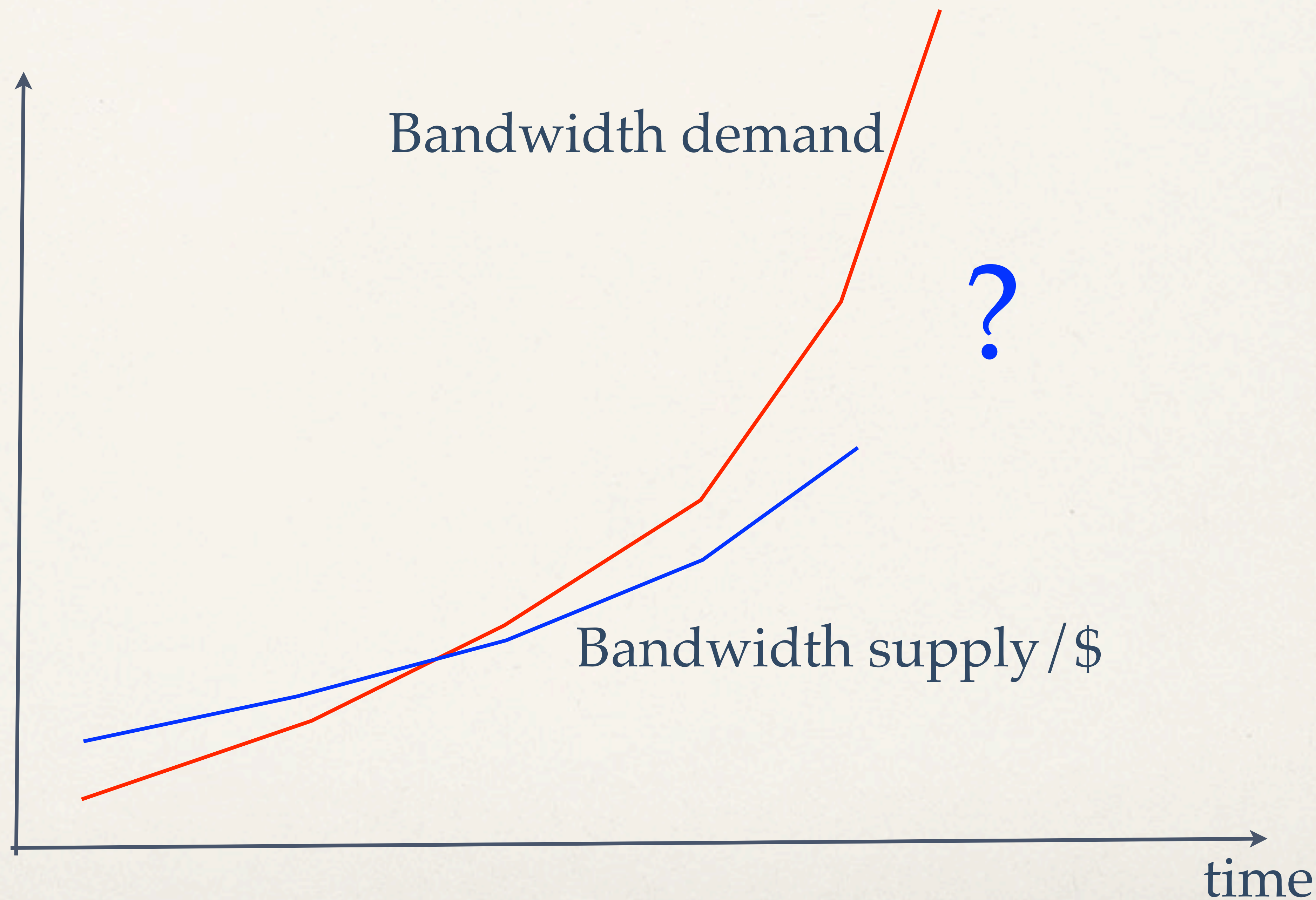
Heterogeneous wireless networks co-existing
Much more complicated ownership issues

The Four Questions

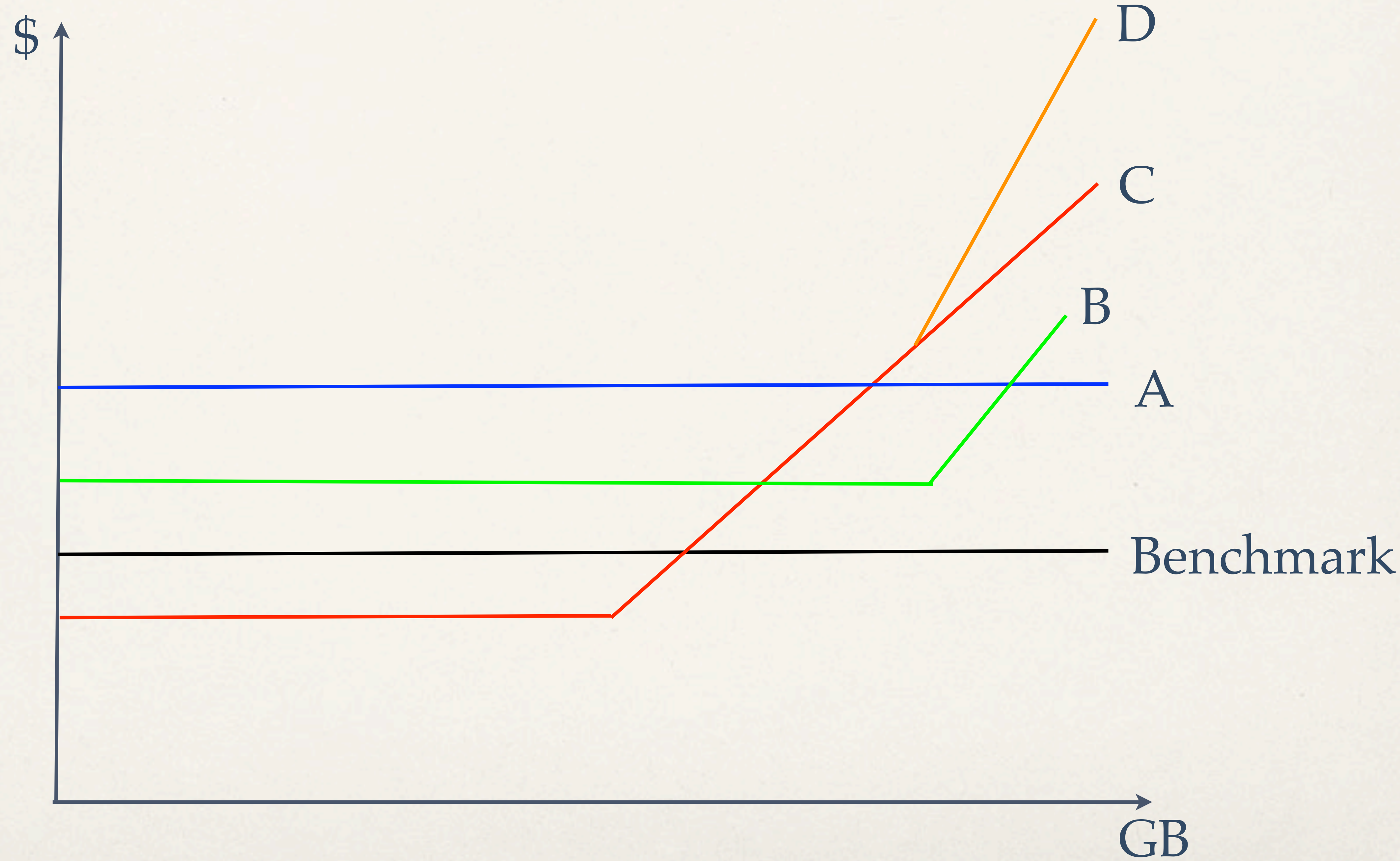
Q1. How Much to Charge?

- From flat rate to usage based (often monthly volume)
  - Tiered-pricing
- Piecewise-linear pricing curves
  - Control flat-rate part or slope of usage-based part
- Flat rate inefficient (e.g., Berkeley INDEX experiment 1998)
- Why did it prevail for so long: attract eyeballs AND

Time for Usage-Based Pricing



A Typical Pricing Graph



A Sample of Utility Model

utility level

1/elasticity

$$U_i(x) = \sigma_i U_{\alpha_i}(x)$$

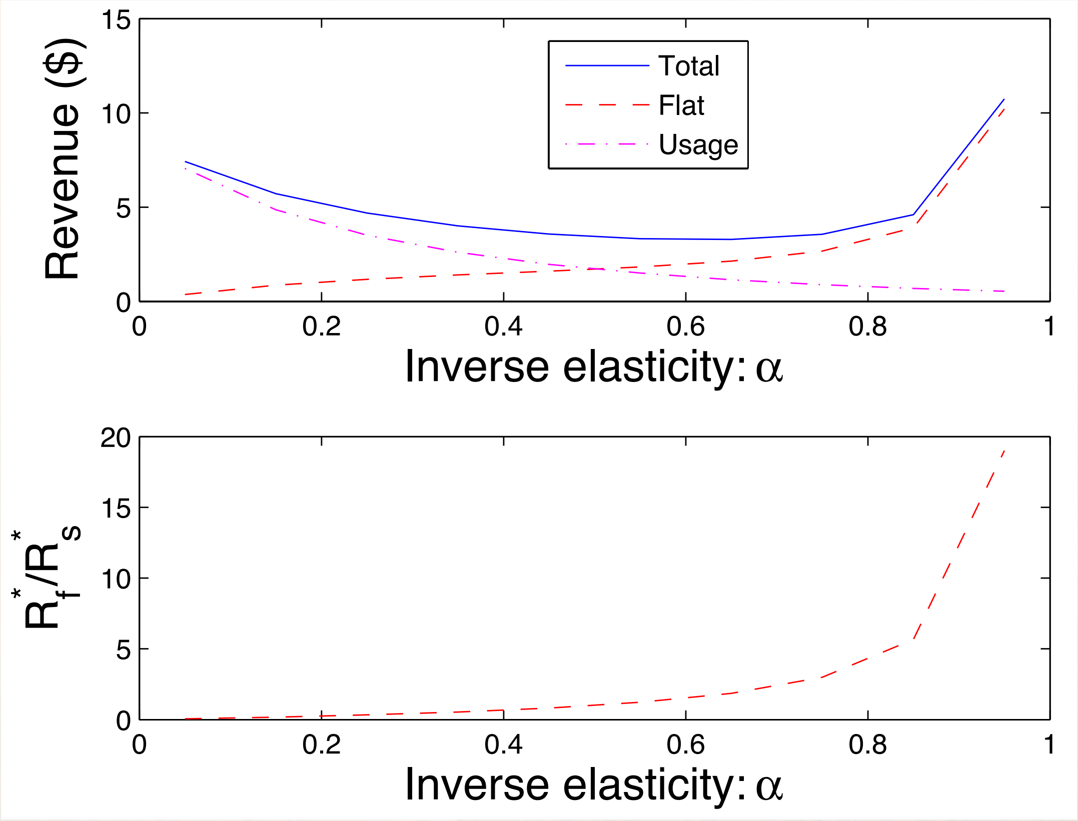
x depends on flow and time

$$U_\alpha(x) = \frac{x^{1-\alpha}}{1-\alpha}, \quad \alpha \neq 1$$

$$= \log x, \quad \alpha = 1$$

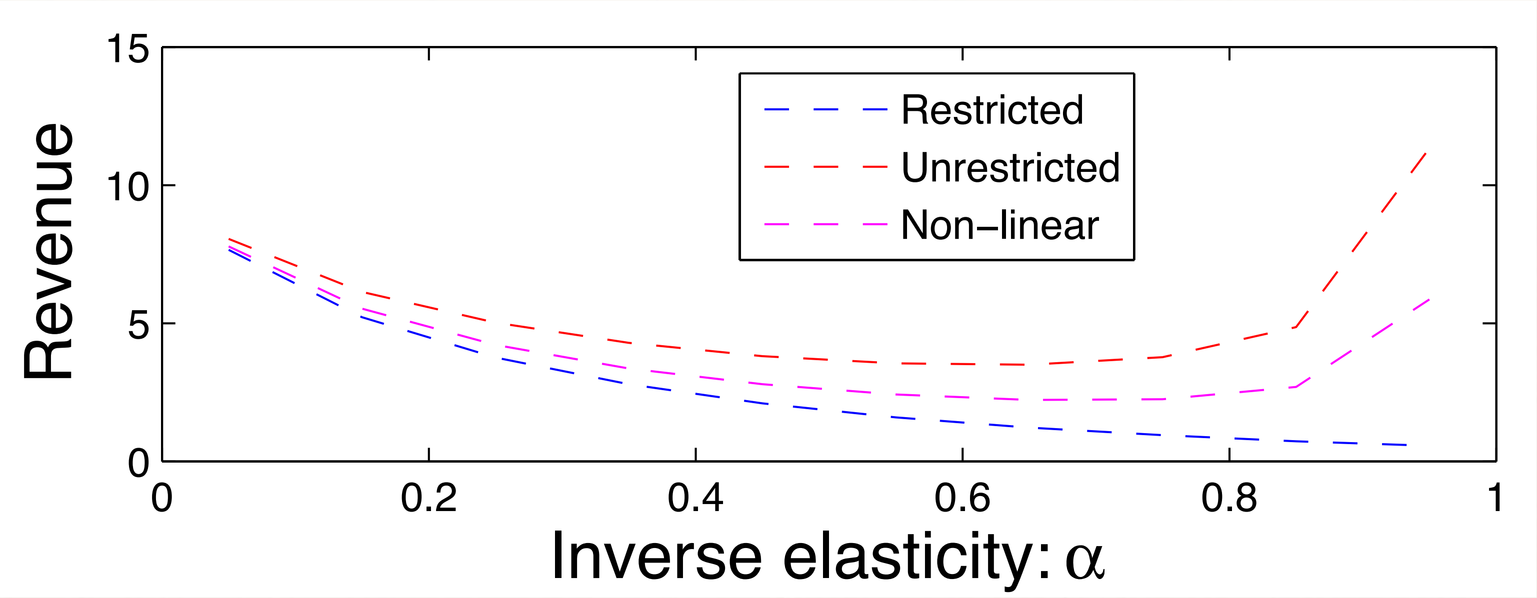
Unconstrained Revenue Max.

- Maximize revenue under hard capacity constraint
  - Flat rate / Usage fee: $$\frac{\alpha}{1-\alpha}$$
- Maximize revenue-capacity cost tradeoff



Constrained Across Flows

- Quantify revenue loss from uniform pricing across flows
  - More loss if consumer demand is less elastic
- Nonlinear pricing (discount at higher rate) mitigates the loss
  - From first to second degree price discrimination

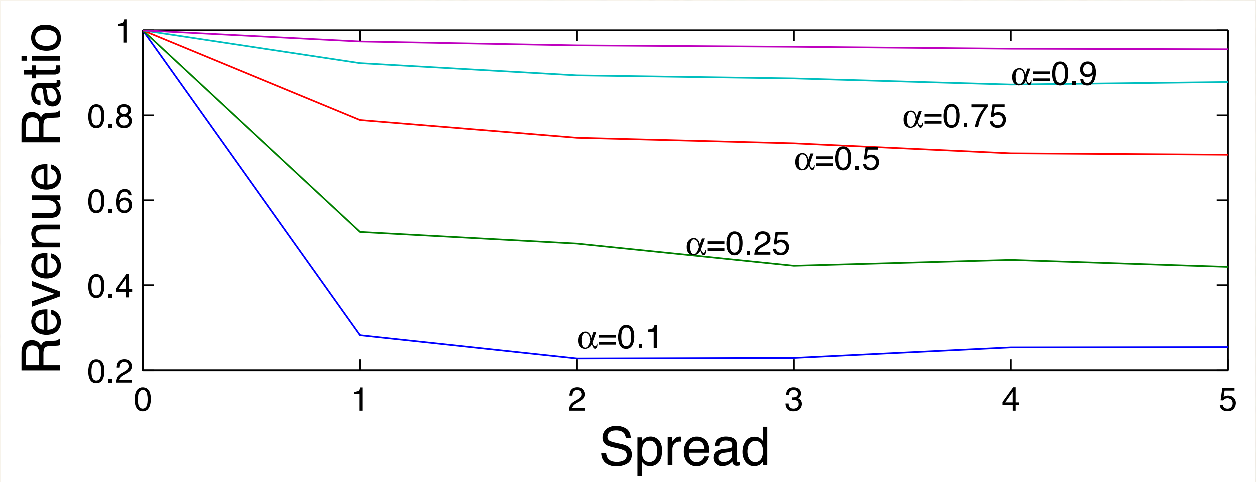


Constrained Over Time

Usage fee depends on traffic volume over a fixed period

Ratio of constrained to unconstrained revenue

$$\frac{\sum_t \left(\frac{\sigma_t}{\sigma^m}\right)^{1/\alpha}}{\sum_t \frac{\sigma_t}{\sigma^m}}$$



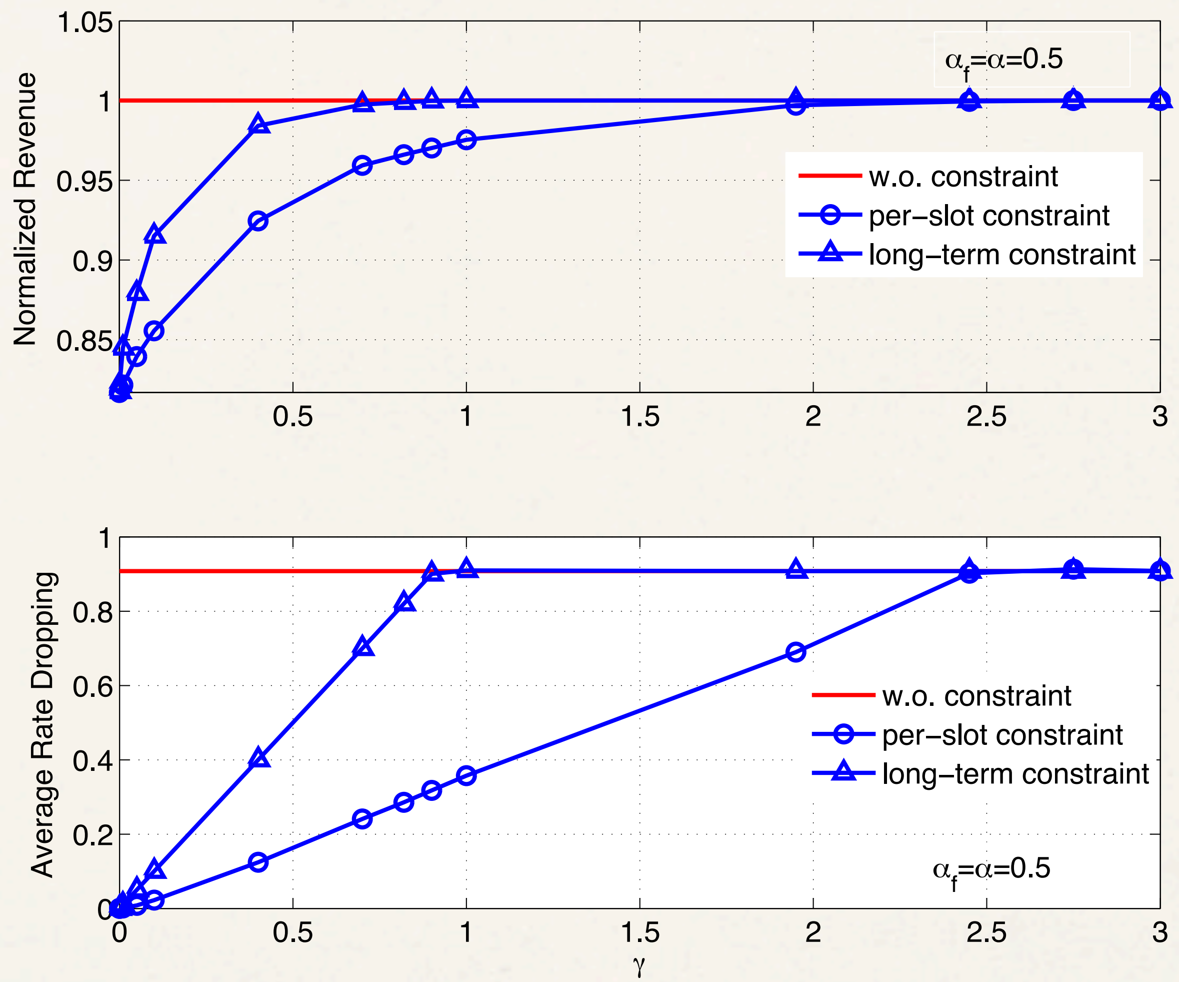
Highly inefficient if utility level has large time spread (later) or high elasticity and no QoS degradation allowed

Two Ways Out

- Set price high -> No congestion -> Revenue loss
- Set price low -> Overfill capacity -> QoS degrades
  - How much? What’s the tradeoff?

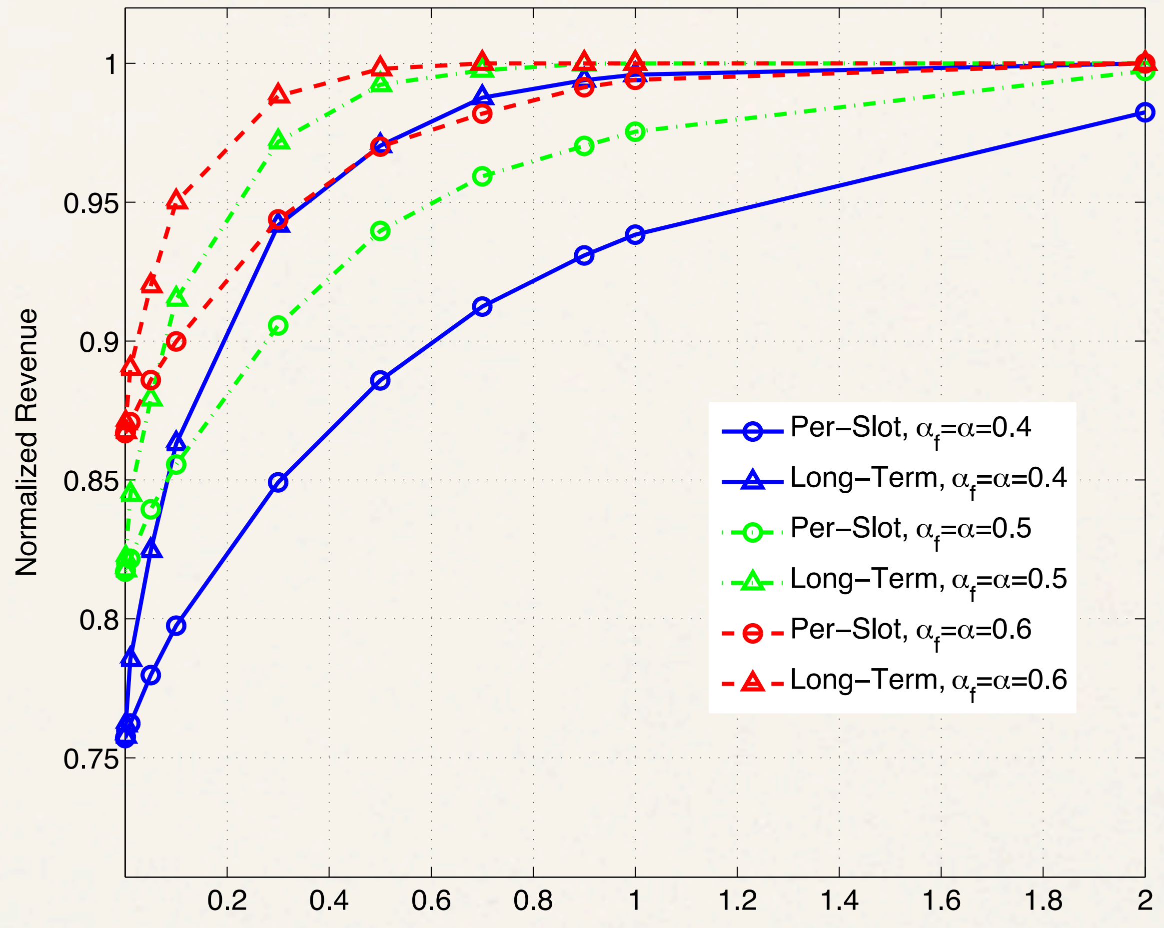
- Set price high -> No congestion -> Sell leftover capacity (later)

Impact of Timescale



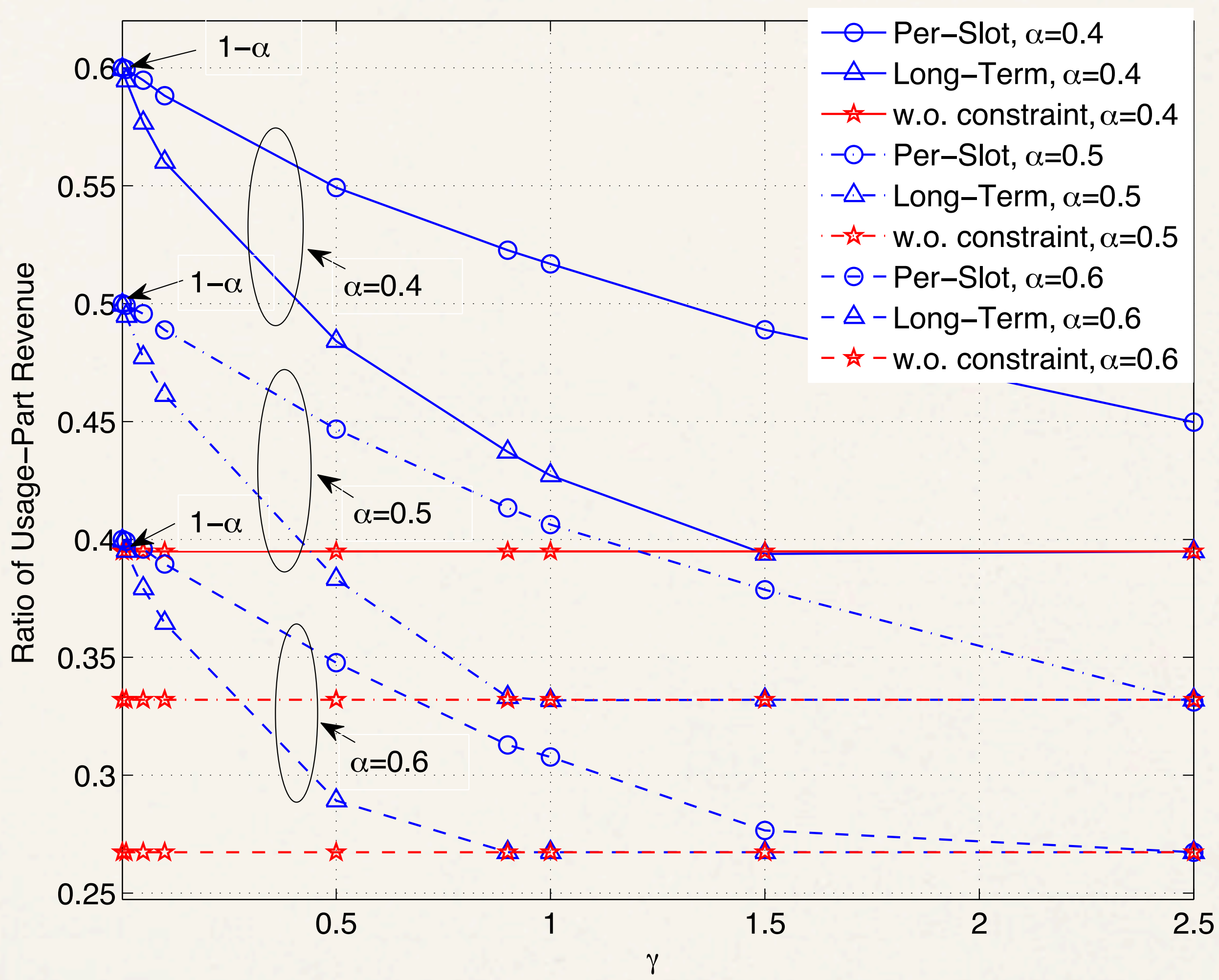
Tight timescale QoS protection -> More revenue loss

Impact of Elasticity



Less elastic demand -> Sweeter revenue-QoS tradeoff

Importance of Flat Price



Ratio of usage price in total revenue drops to a constant as QoS requirement loosens

The constant fraction is less as elasticity decreases

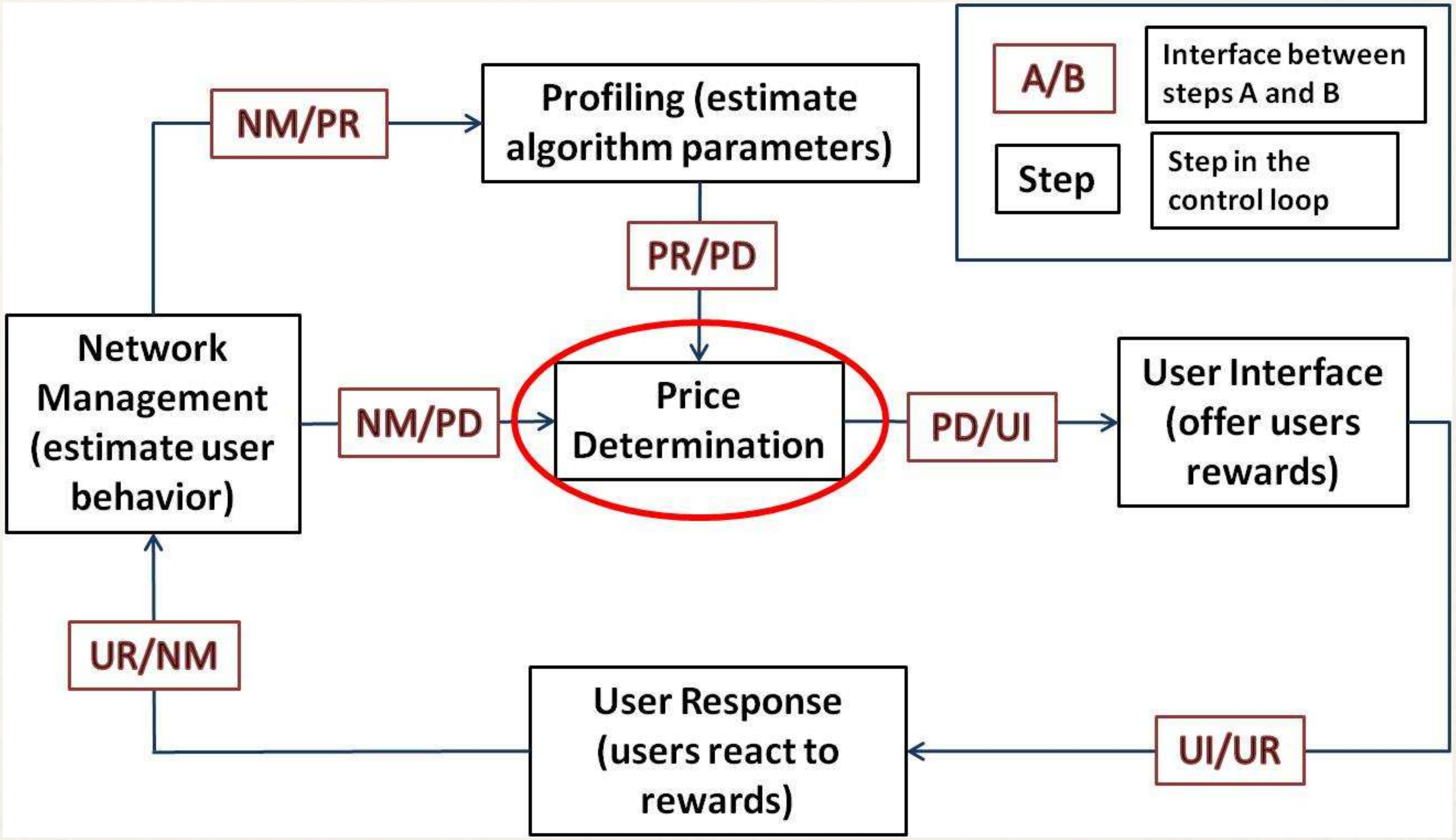
Q2. How to Charge?

- Next step: Time dependent pricing
  - Extension: Congestion dependent pricing
- Time-series shaper: from current 24-hour curve to desired shape
  - Bring “tail” and “mean” (on time axis) closer
- How to make it “work”?
  - Compare with current practice of binary time-dependent pricing
  - Compare with time-of-usage pricing in utility industry

Key Factors

- ISP's perspective: balance two costs
  - Cost of worst-case capacity provisioning (capital expenditure)
  - Cost of "rewarding" users willing to shift their traffic (recurring)
- User's perspective:
  - "Time elasticity" depends on time sensitivity of traffic
  - And user's patience level
- How to incorporate user elasticities and optimize price efficiently?

Schematic



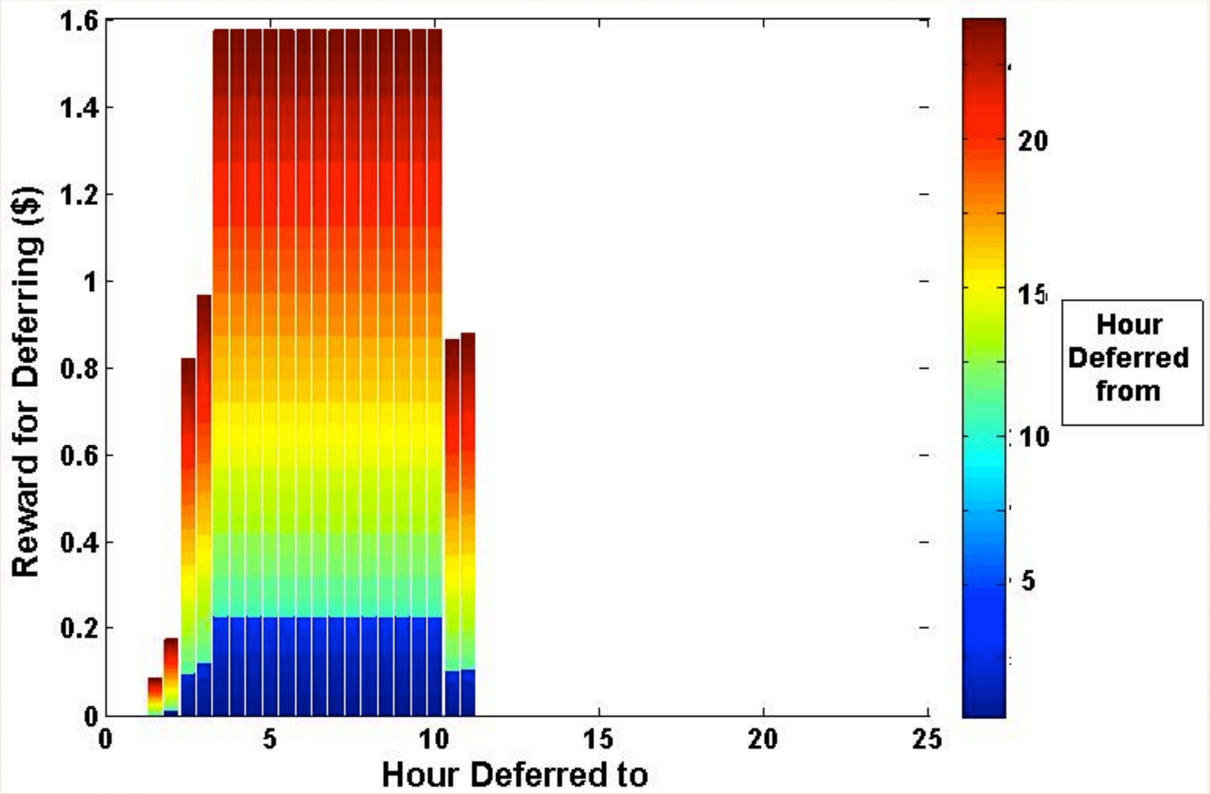
A/B
Interface between steps A and B
Step
Step in the control loop
NM/PR
Profiling (estimate algorithm parameters)
PR/PD
Network Management (estimate user behavior)
NM/PD
Price Determination
PD/UI
User Interface (offer users rewards)
UR/NM
User Response (users react to rewards)
UI/UR

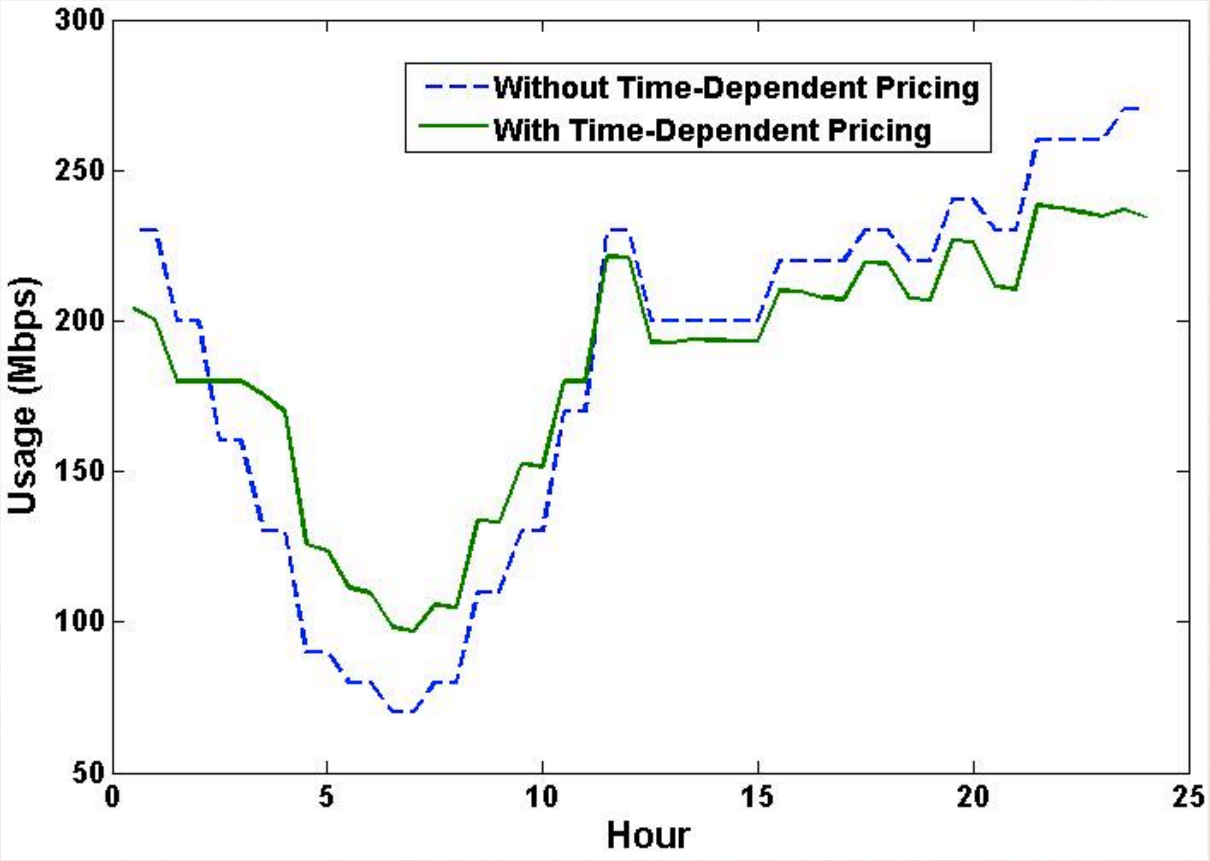
Some Challenges

- General number of time slots (e.g., 48)
- User patience function $w(p(\tau), \tau)$ rather than "representative demand function" per time slot
- Arrival and departure dynamics

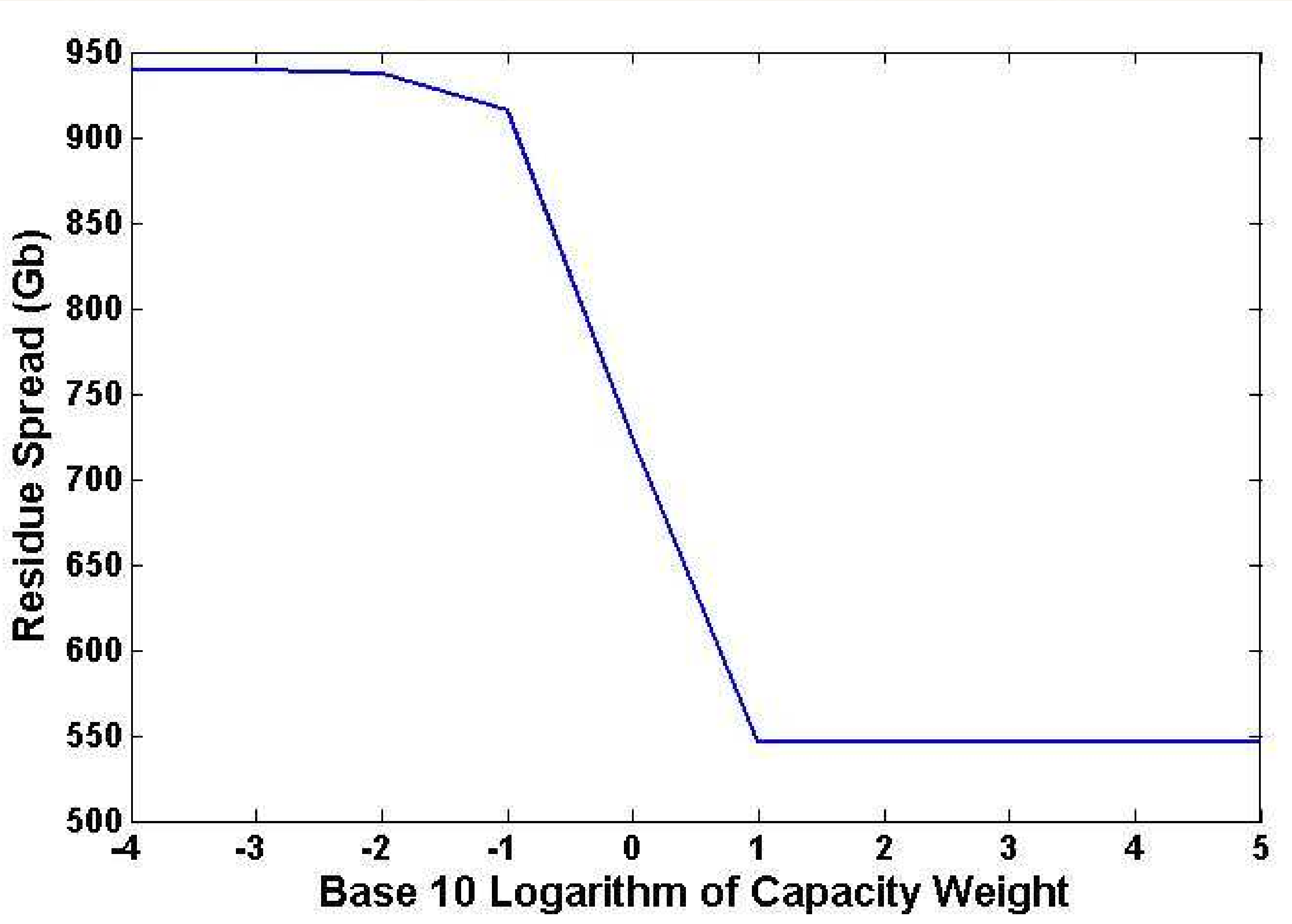
- Search for an representation leading to efficient computation
- Turns out to be possible

Levelling in Action





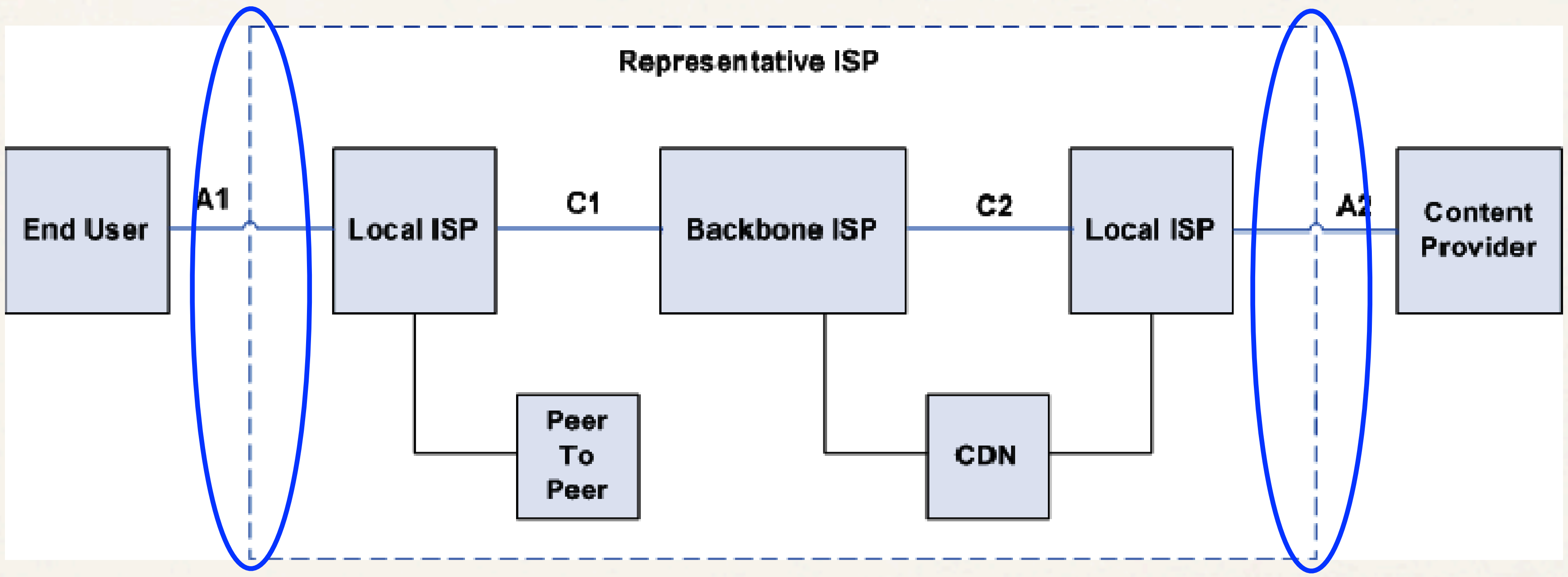
Impact of Congestion Definition



Heavier emphasis on congestion alleviation leads to more levelling

Eventually saturates at a level determined by user elasticities

Q3. Whom to Charge?



- Two sided pricing
- Extreme case: 1-800 service of free Internet access
- CP interest: Elasticity-cost points just right for volume play

Key Factors

- EU: utility maximization (of rate, volume, etc)
- CP: utility maximization
- ISP: max (revenue - bandwidth cost)
  - Competitive or monopoly ISP
- Examine equilibrium behaviors
  - Single ISP
  - Inter-connected multiple ISPs

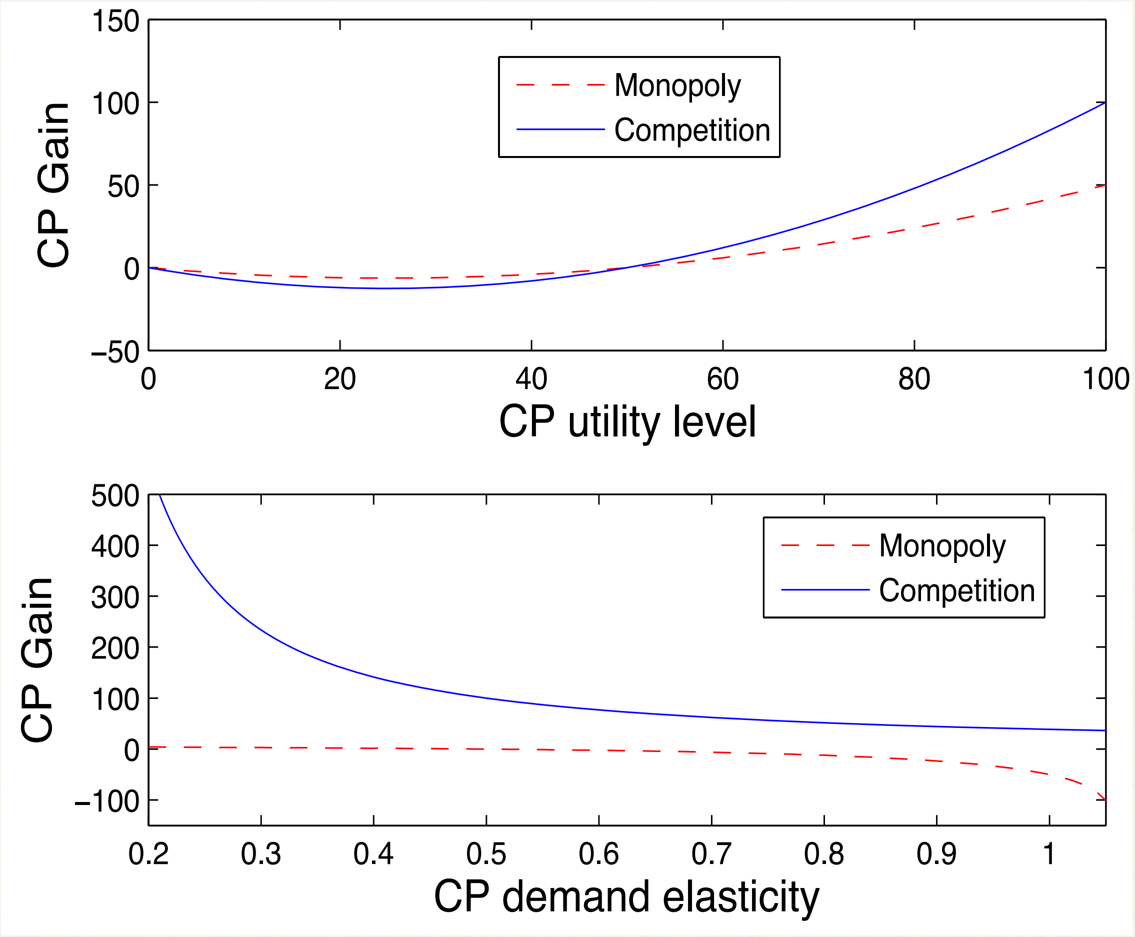
An Example

b_f	ISP Competition	
	EU Price	EU Demand
0	\$50	1.0 Mbps
20	\$36	2.0 Mbps
40	\$28	3.25 Mbps
60	\$23	4.84 Mbps
80	\$19	6.76 Mbps
100	\$17	9.0 Mbps

β_f	ISP Competition	
	EU Price	EU Demand
0.2	\$6	63 Mbps
0.4	\$14	13 Mbps
0.6	\$19	7 Mbps
0.8	\$22	5 Mbps
1.0	\$25	4 Mbps
1.05	\$26	3.8 Mbps

CP utility level (or elasticity) increases, EU pays less and demands more

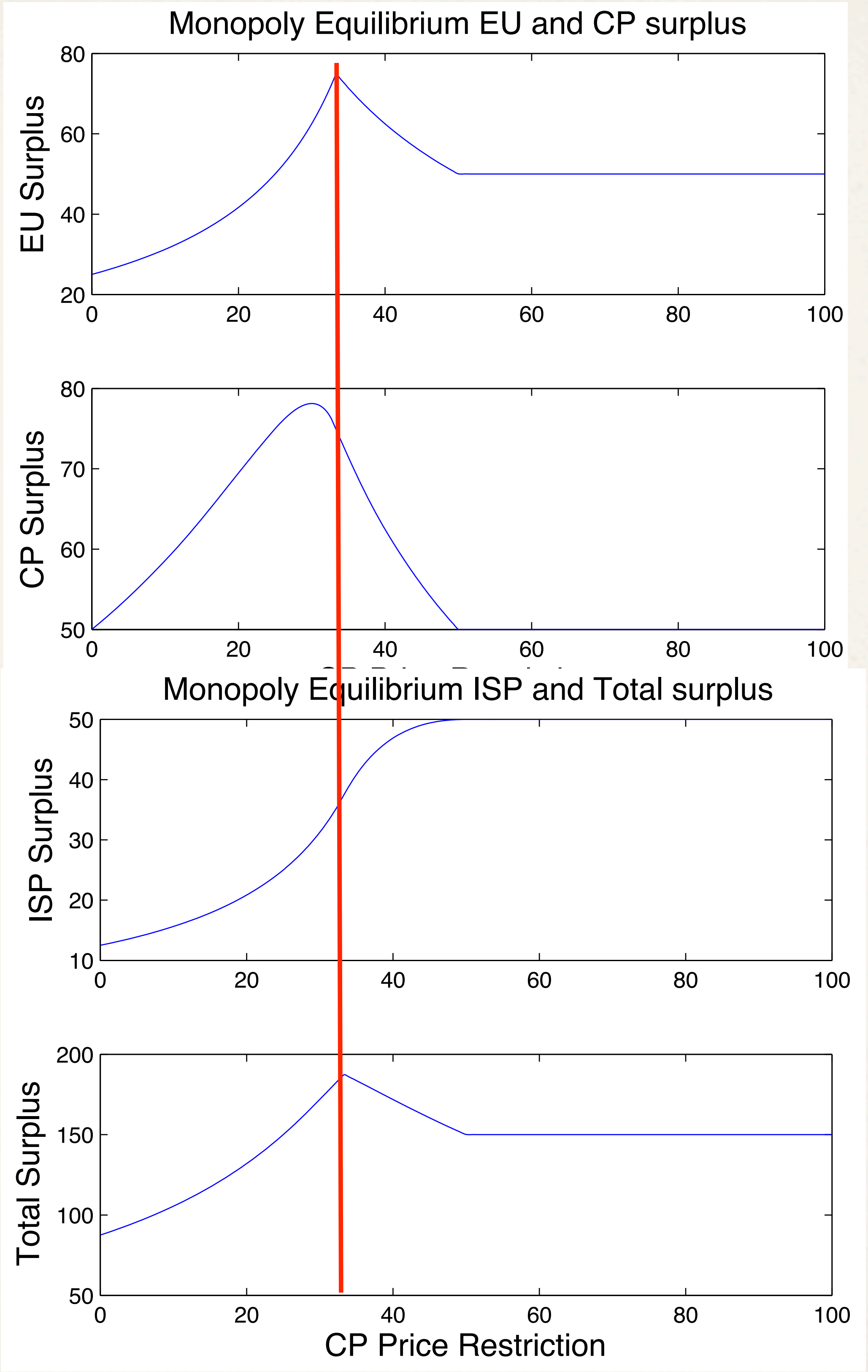
When Will CP See Benefit?



Under ISP competition and low enough CP elasticity, CP gains a lot

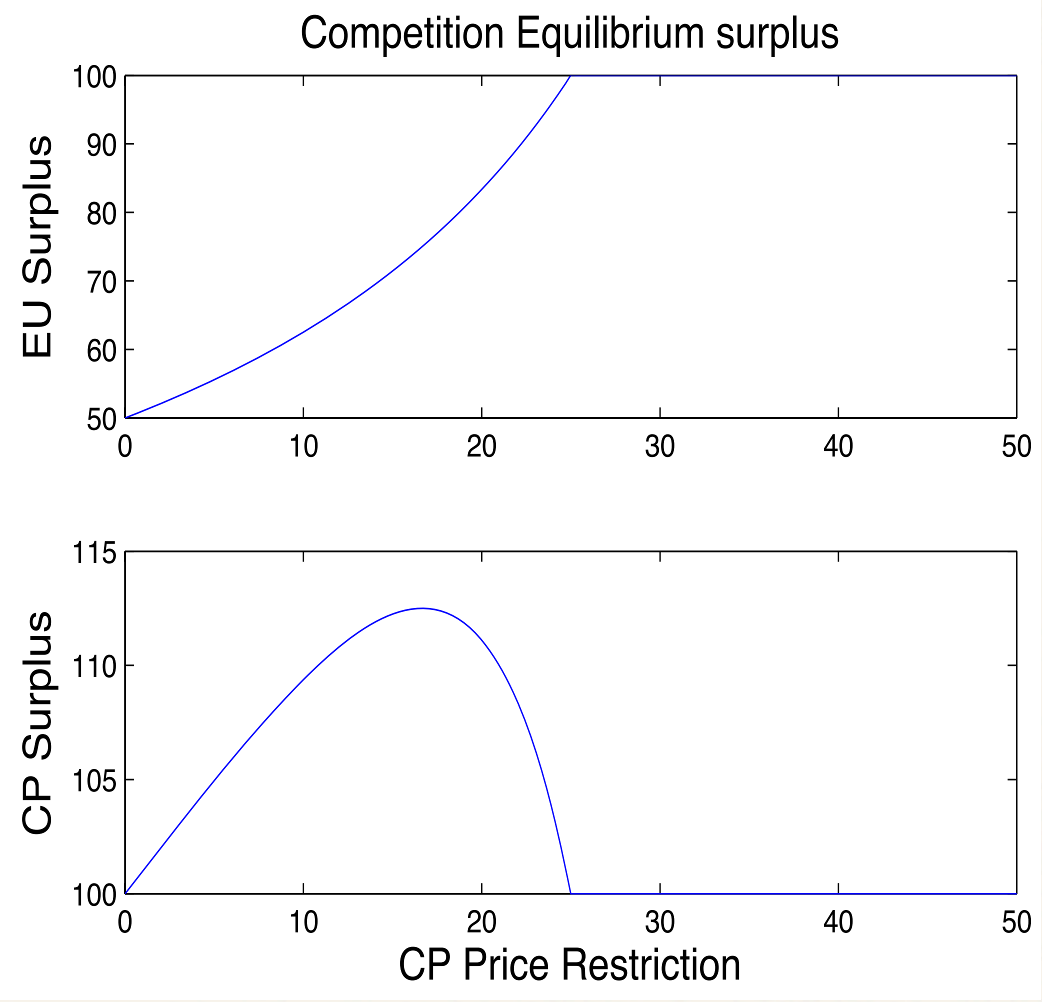
Model net neutrality via CP price restriction

Monopology ISP Case



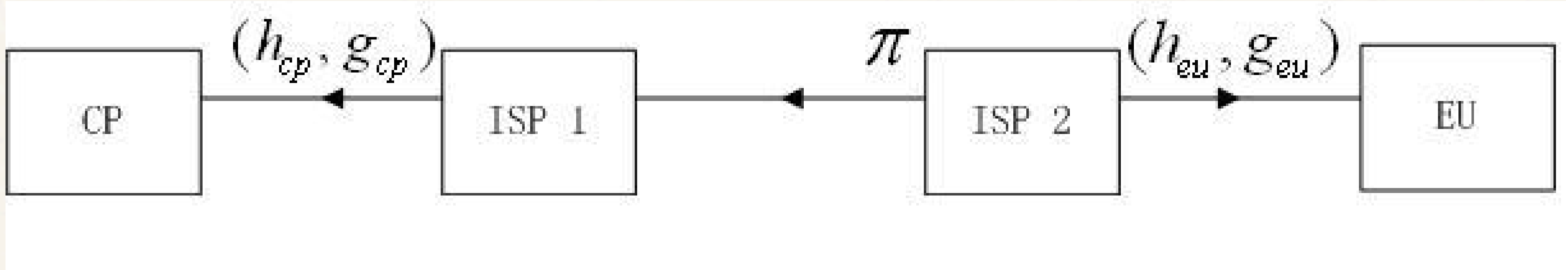
Relax the price restriction -> Impact on surplus and its distribution

Competitive ISP Case



Charging CP (1) increases EU surplus
(2) leaves ISP surplus the same
(3) increases CP surplus if EU elasticity high compared to connectivity cost

Inter-ISP Pricing



Biased position on traffic delivery chain

Cooperative:

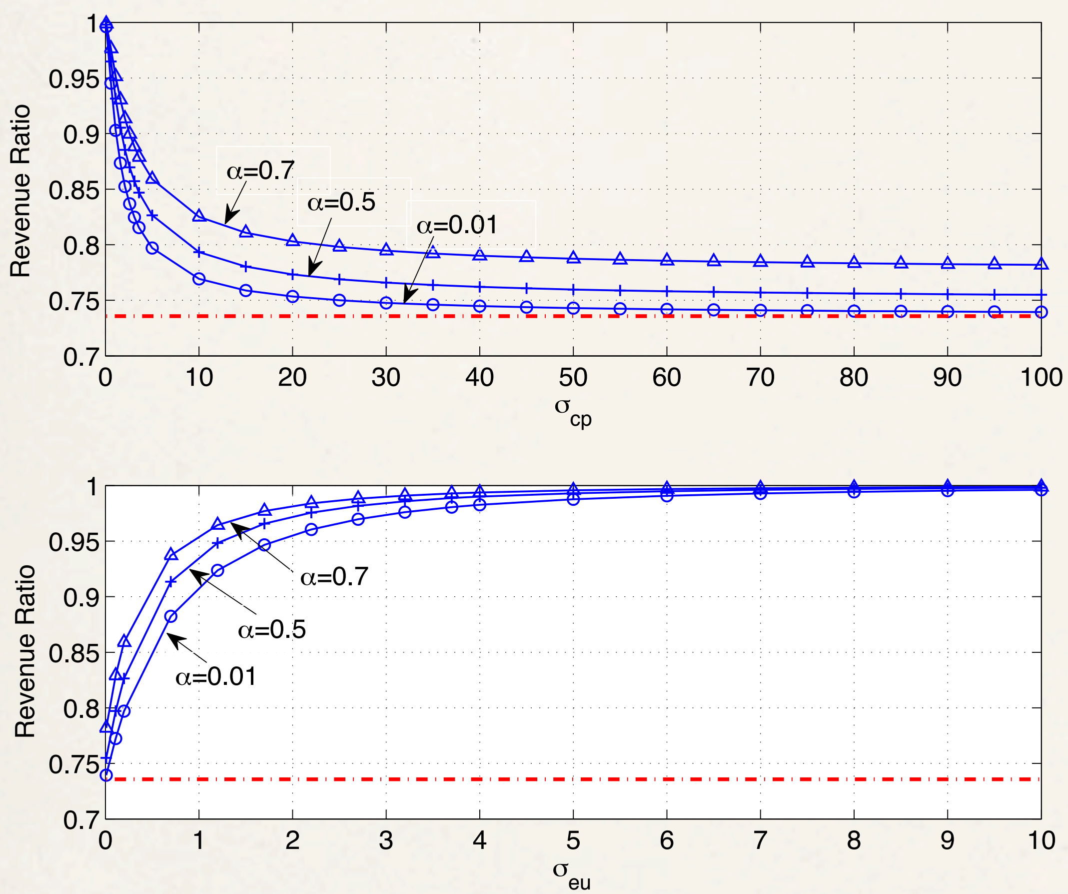
Revenue sharing contract: dominant ISP asks for transit price lower than marginal traffic delivery cost, plus lump-sum sharing of other ISP revenue

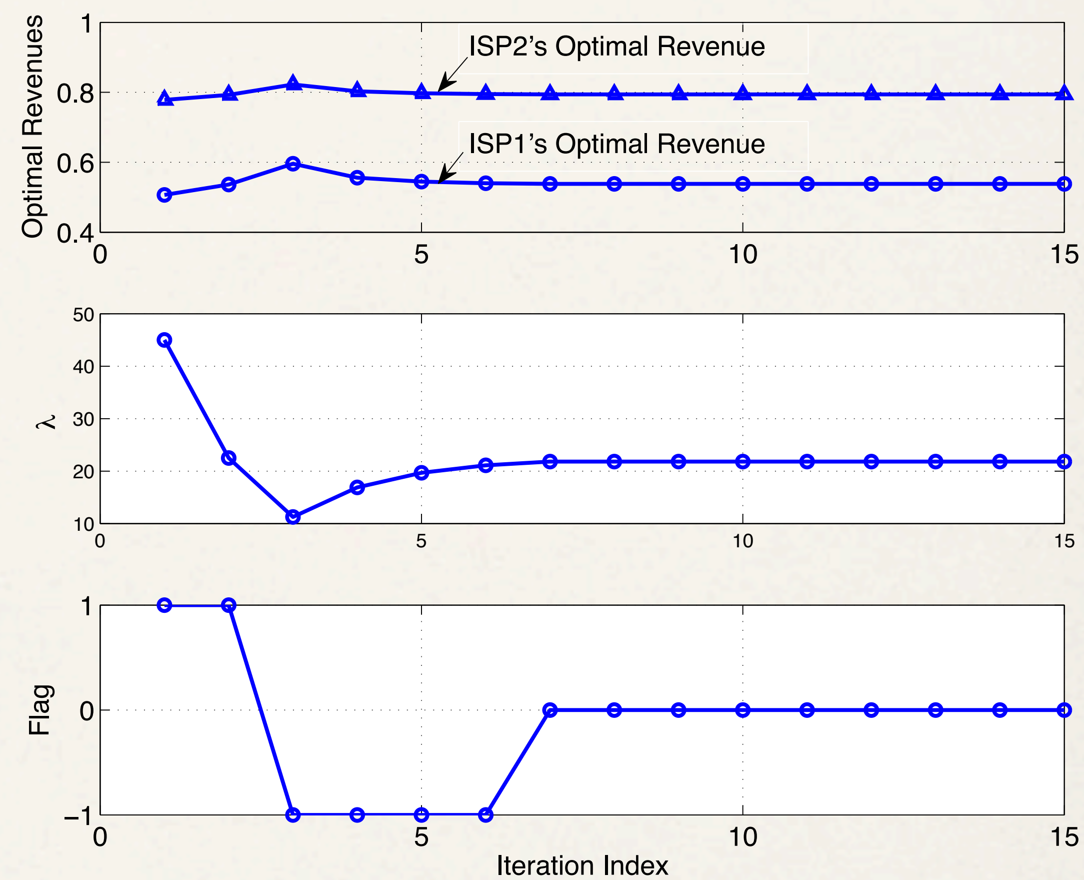
Non-cooperative:

Quantify lost social revenue

Asymmetric NBS to improve both ISPs

Non-cooperative and Bargaining





Stackelberg model:
EU-facing ISP is the leader

Example of asymmetric bargaining
converging to global optimum

Q4. What to Charge?

- Different services -> Different prices
- New service types:
  - Package service
  - User-specific service
  - Emergency service

New Connectivity Services

- Create new class of services: Scavenger class of service
  - Fill in the leftover capacity. Particularly helpful for wireless
  - Minimum utility level needed to recover revenue loss due to constraint over time
- $5/month data plans
  - No guarantee on near-instantaneous access
  - Precise QoS depends on how crowded $5/month plan users are

Paris Metro Pricing

- Differential prices -> Differential services
  - Origin: Odlyzko 2000...
  - Survey: Walrand 2008...
  - Recent development: Chiu Lui et al. 2010...

Pricing Across Hetero Wireless

- Co-existence of multiple wireless platforms owned by different ISPs:
  - 3G/4G, Femto, WiFi
- Price bundling: pricing for stickiness
- Price differentiation: offload licensed band congestion
  - Interaction with interference management on technological plane
  - Mobility and hand-off support
  - May enable the dissolution of cellular industry’s vertical mode

From Theory To Practice

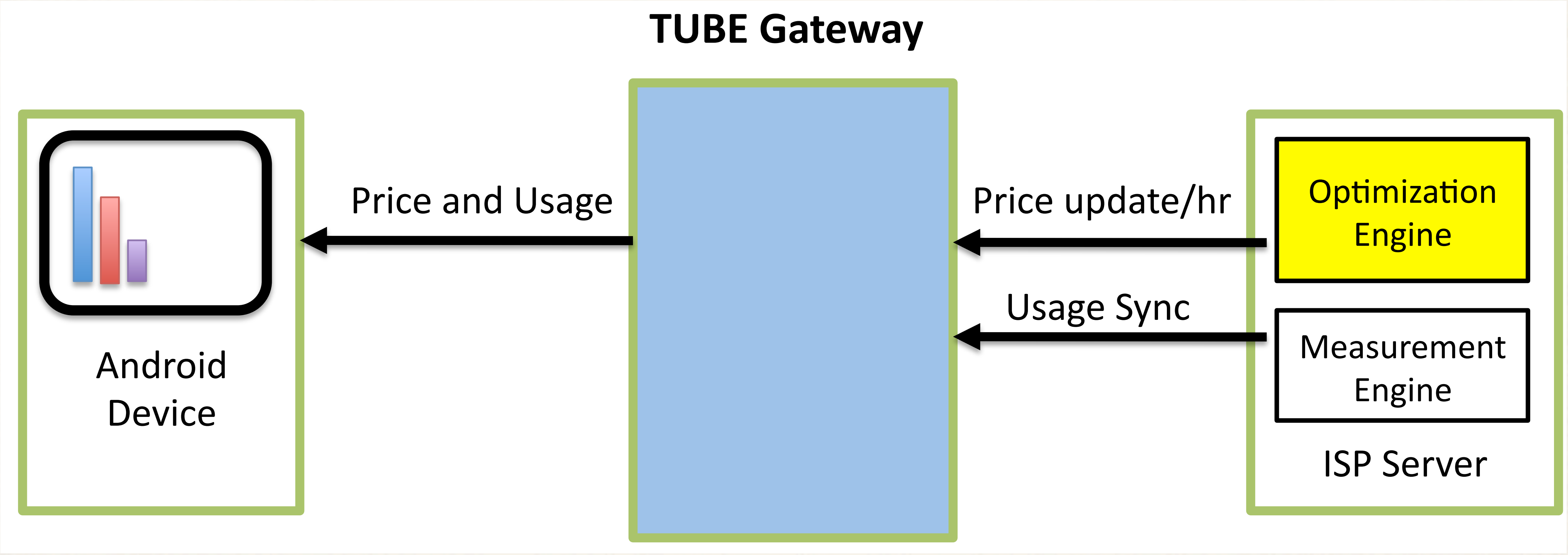
Model/Analysis is Only 1 Step

- Data, Data, Data
- Prototyping proof-of-concept
- Field trial and industry adoption
- Public education and policy impact
    - NECA-EDGE Lab whitepaper June 2010

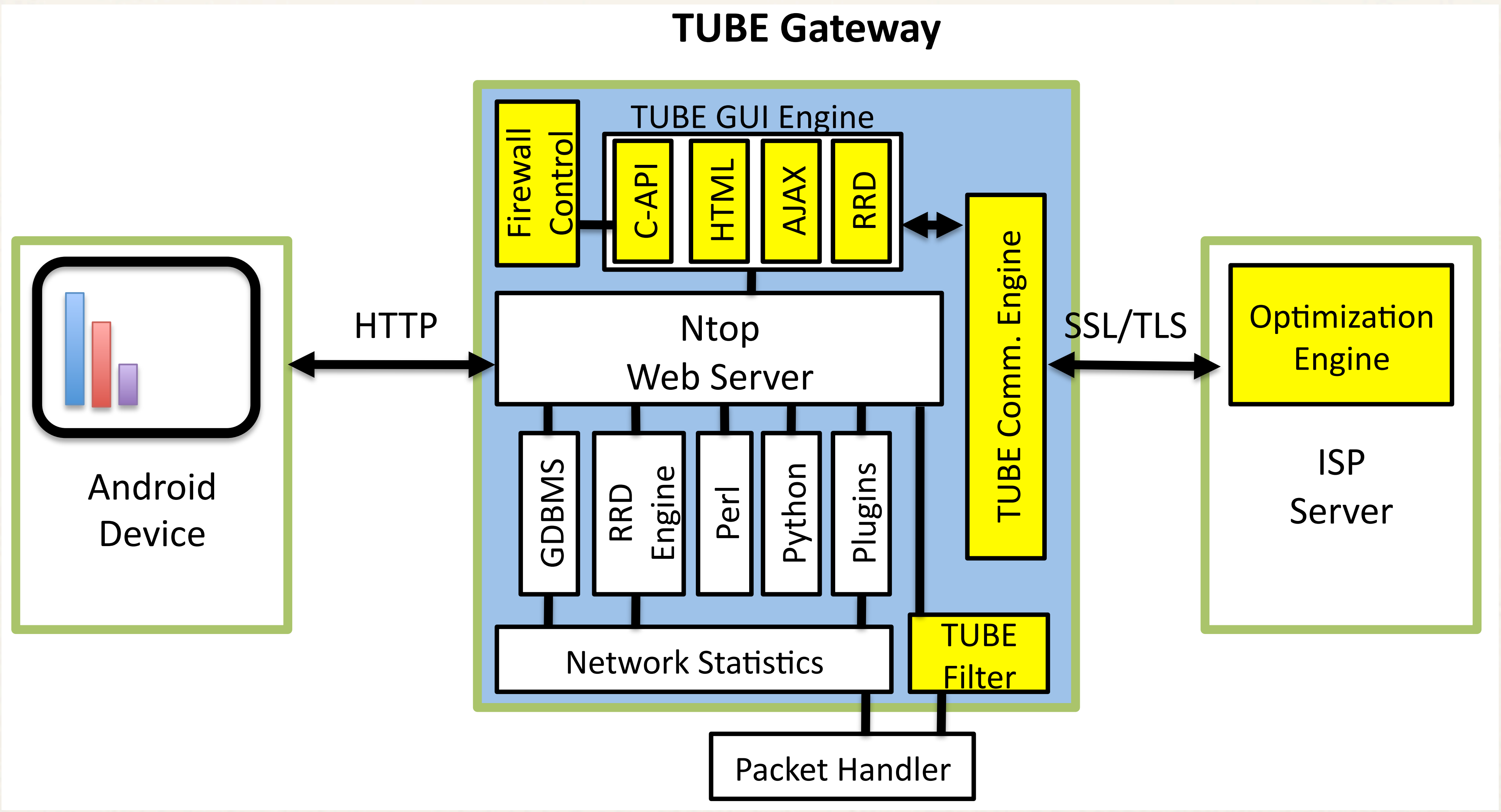
TUBE

- Time-dependent Usage-based Broadband-price Engineering
  - Measurement
  - Price optimization engine
  - User interface
- User profiling
- Recommendation
- Wireless extension

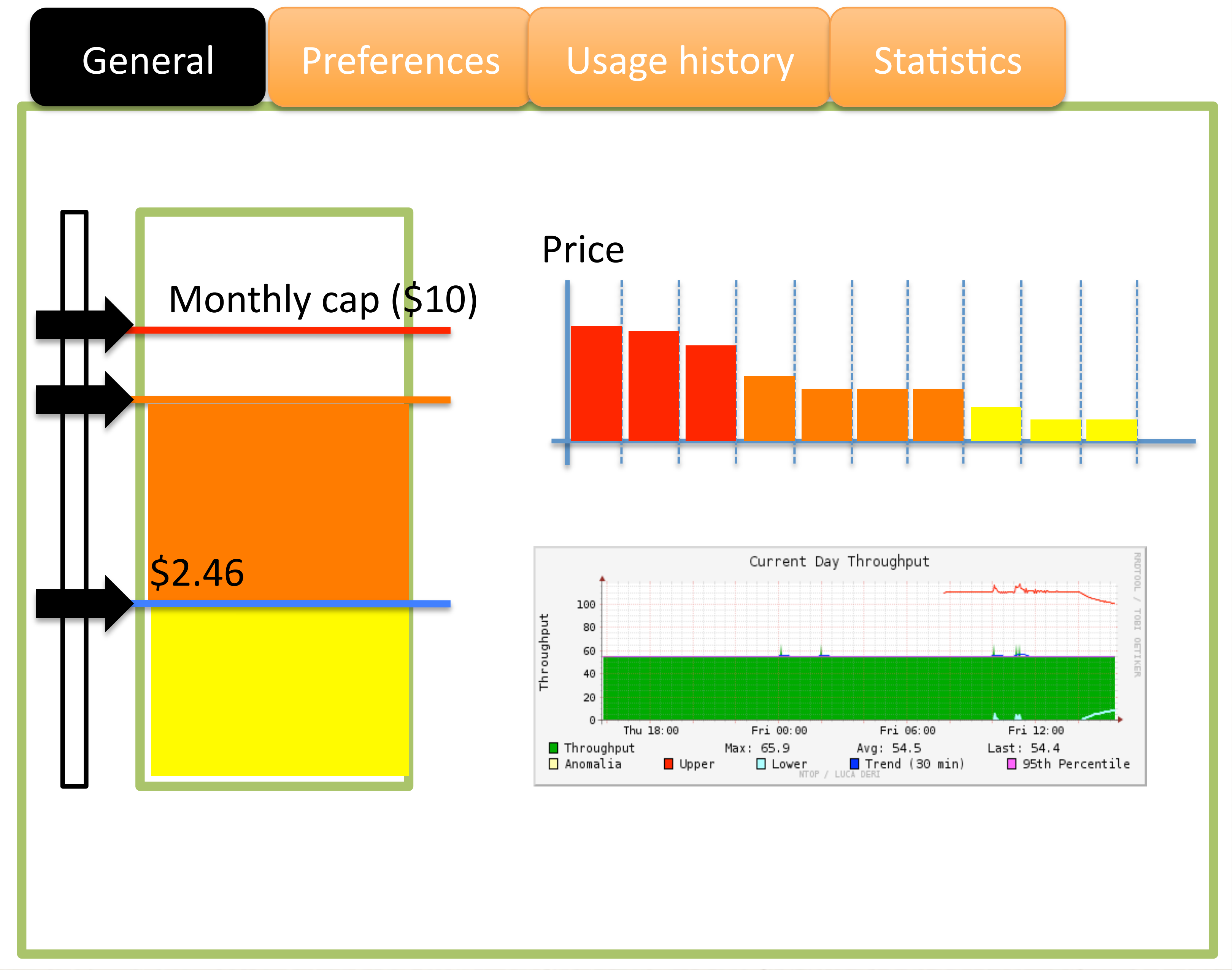
TUBE Architecture



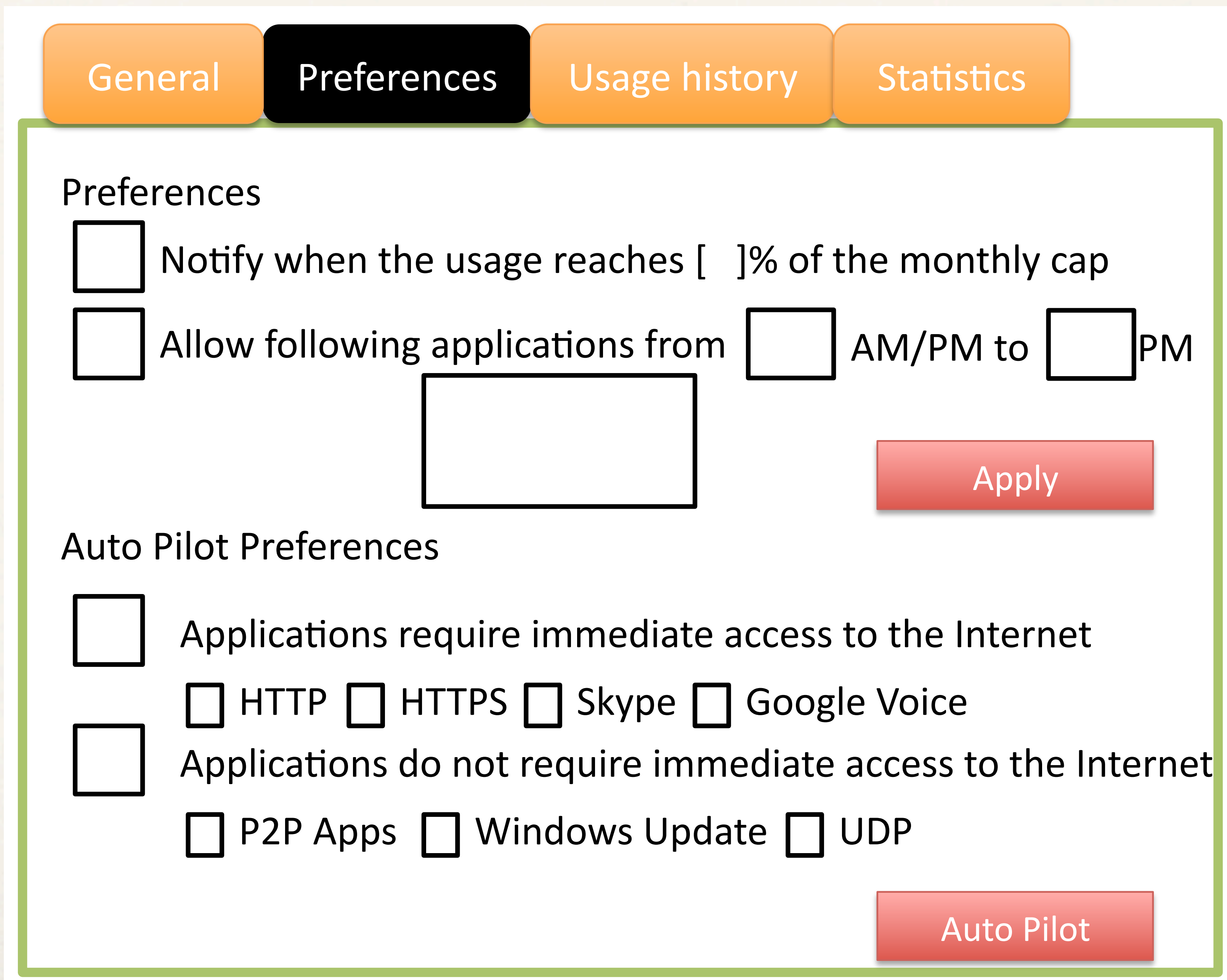
TUBE Architecture



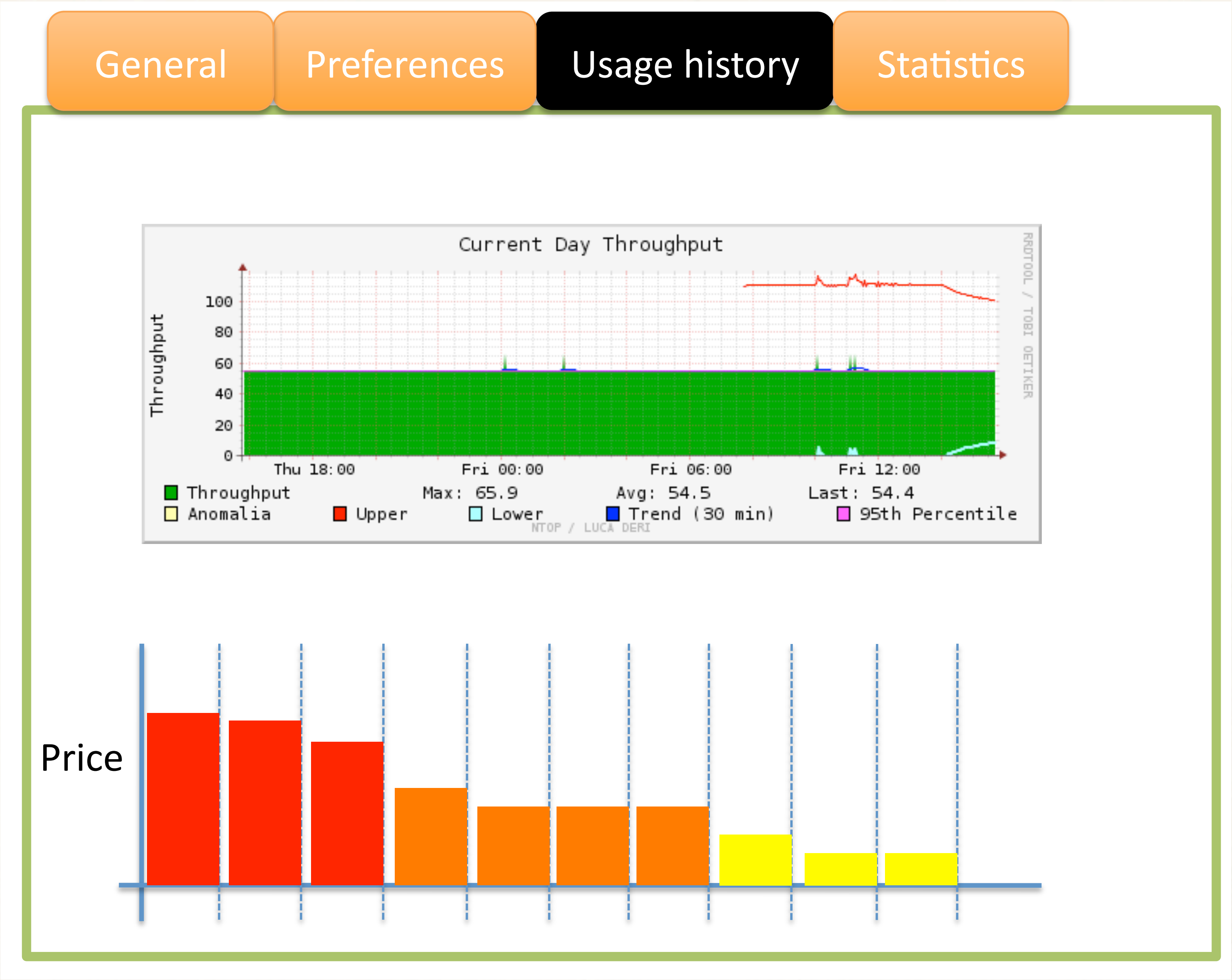
TUBE UI


General
Preferences
Usage history
Statistics
Monthly cap ($10)
$2.46
Price
Current Day Throughput
Throughput
100
80
60
40
20
0
Thu 18:00
Fri 00:00
Fri 06:00
Fri 12:00
Throughput
Max: 65.9
Avg: 54.5
Last: 54.4
Anomalia
Upper
Lower
Trend (30 min)
95th Percentile

TUBE UI

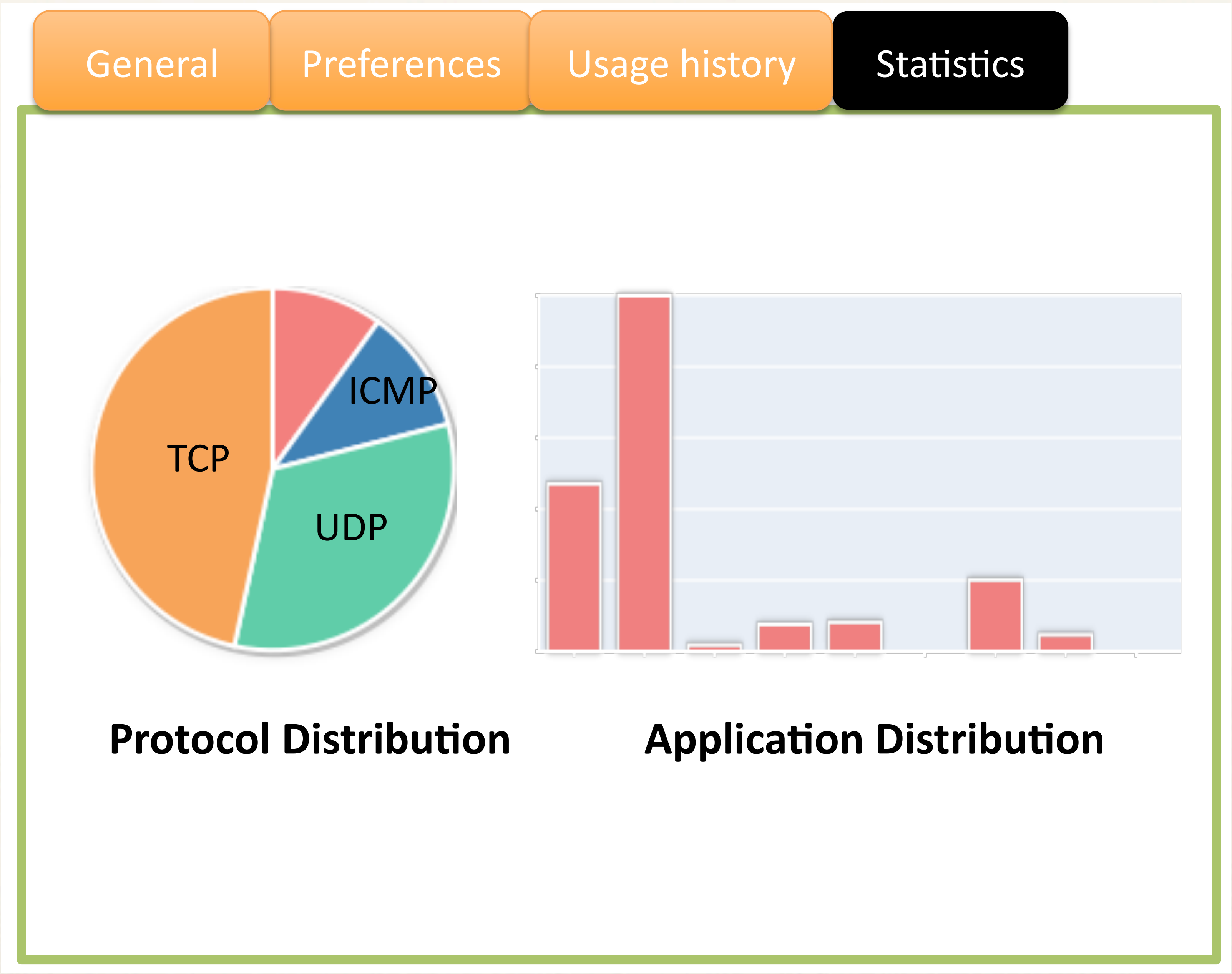

General
Preferences
Usage history
Statistics
Preferences
Notify when the usage reaches [ ]% of the monthly cap
Allow following applications from
AM/PM to
PM
Apply
Auto Pilot Preferences
Applications require immediate access to the Internet
HTTP
HTTPS
Skype
Google Voice
Applications do not require immediate access to the Internet
P2P Apps
Windows Update
UDP
Auto Pilot

TUBE UI



General
Preferences
Usage history
Statistics
Current Day Throughput
Throughput
100
80
60
40
20
0
Thu 18:00
Fri 00:00
Fri 06:00
Fri 12:00
Throughput
Max: 65.9
Avg: 54.5
Last: 54.4
Anomalia
Upper
Lower
Trend (30 min)
95th Percentile
Price

TUBE UI



General
Preferences
Usage history
Statistics
TCP
ICMP
UDP
Protocol Distribution
Application Distribution

Data Collection and Analysis

- Utility Function/Demand Function/Elasticity construction from empirical data and proxies
- Different speed tiers/service offerings impact elasticity a lot
- Substantial statistical challenges
- NECA-Princeton Surveys and Polls to ISPs

Partners

- Data sources and deployment outlets:
  - NECA
  - AT&T
  - Small ISPs
  - Princeton trial user base

Acknowledgements

- Sangtae Ha, Carlee Joe-Wong (Princeton)
- Rob Calderbank, Prashanth Hande, Hongseok Kim (Formerly P)
- Raj Savoor, Steve Sposato and group (AT&T)
- Victor Glass and group (NECA)
- Junshan Zhang (ASU)
- Yuan Wu, Danny Tsang (HKUST)

What We Need (Most)

Challenges in Access Pricing Study

- Model/theory on
  - User profiling: utility and irrationality
  - ISP cost and cooperation/competition in inter-ISP scenarios
- Theory falsification by data
  - Start with falsifiable theory
- Market impact by deployment
  - Start with small user base trials

Your Research Changes Your Bill

Quick Bill Summary Sep 17 – Oct 16

Previous Balance *(see back for details)*	$225.69
Payment – Thank You	–$225.69
Balance Forward	**$.00**
Monthly Access Charges	$153.96
Usage Charges	
Voice	$.00
Messaging	$10.40
Data	$21.97
Verizon Wireless' Surcharges and Other Charges & Credits	$5.70
Taxes, Governmental Surcharges & Fees	$11.50
Total Current Charges	**$203.53**
Total Charges Due by November 11, 2010	**$203.53**

Guaranteed express delivery

Data		**Allowance**	**Used**	**Billable**	**Cost**
~~Premium Messaging~~	~~*messages*~~	--	1	1	9.99
Other Charges	*minutes*	--	1	1	1.99
Kilobyte Usage	*kilobytes*	unlimited	2608		
Total Data					$11.98
Total Usage Charges					**$22.18**

Usage price $50.99

Verizon Wireless' Surcharges	
Fed Universal Service Charge	.59
Regulatory Charge	.13
Administrative Charge	.83
	$1.55

Some of the 45 types of taxes I pay

Taxes, Governmental Surcharges and Fees	
NJ 911 System/Emerg. Resp. Fee	.90
NJ State Sales Tax	2.35
	$3.25

Charges

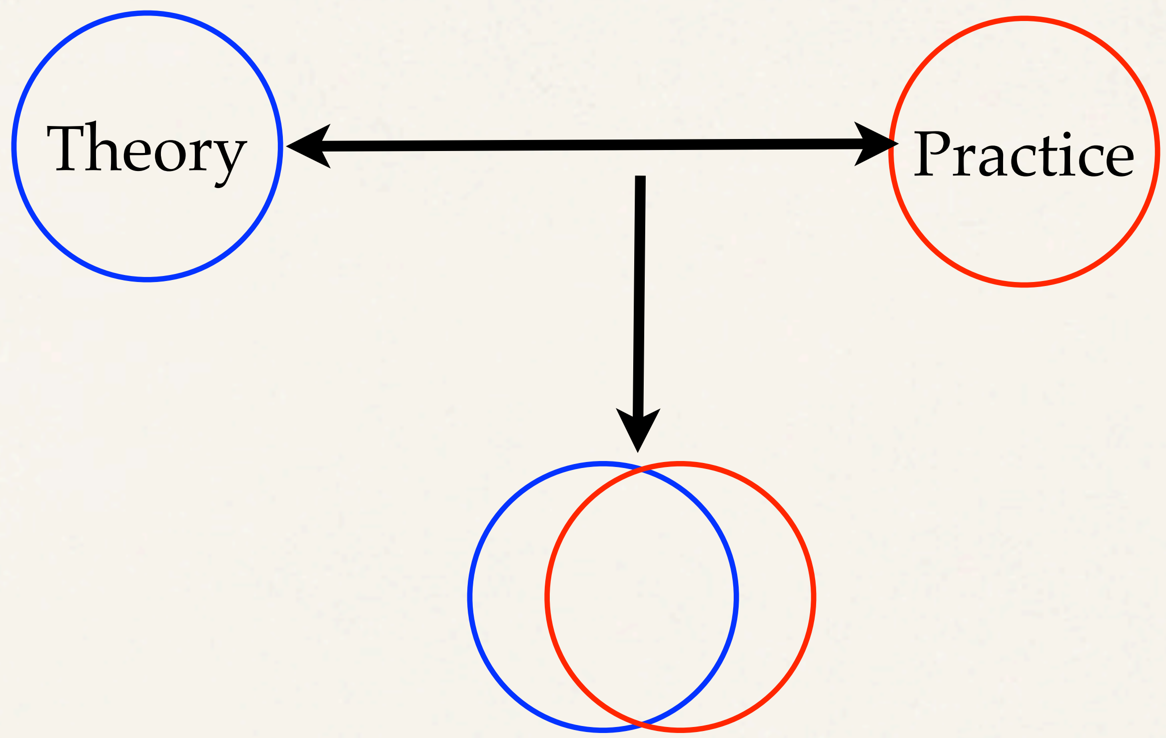
Monthly Access Charges	
AC Family SharePlan 1400 10/17 – 11/16	80.00
~~15% Access Discount 10/17 – 11/16~~	12.00
BlackBerry Unlimited BBA 10/17 – 11/16	44.99
20% – Feature Discount 10/17 – 11/16	–9.00
	$103.99

paid in part by Apple

Time of usage discount $69.88

Usage Charges

Voice		**Allowance**	**Used**	**Billable**	**Cost**
SharePlan	*minutes*	1400 (shared)	203	--	--
Mobile to Mobile	*minutes*	unlimited	162	--	--



http://scenic.princeton.edu

The Princeton EDGE Lab