

Trade & Cap: A Customer-Managed, Market-Based System for Trading Bandwidth Allowances at a Shared Link

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Today's last mile

High Speed Internet		FIOS Internet			
Starter	Power	Turbo	Fast	Faster	Fastest
STARTING AT \$19.99/mo	STARTING AT \$29.99/mo	STARTING AT \$39.99/mo	STARTING AT \$49.99/mo	STARTING AT \$64.99/mo	STARTING AT \$139.95/mo
• 1 Mbps • 304 Kbps	• 3 Mbps • 768 Kbps	• 7.1 Mbps • 768 Kbps	• 15 Mbps • 3 Mbps	• 20 Mbps • 25 Mbps	• 30 Mbps • 20 Mbps
• Stream online	• Online gaming	• Fastest DSL	• Fast gaming	• Stream HD video	• Download FIOS
• Check email	• Downloading purchased songs, ebooks, large files	• Download large files	• Streaming video	• Download extra-large files	• Great for all kinds of work and play
• Downloaded email files	• Working from home	• Great for working from home	• Downloaded files in seconds	• Fine for everything else	• Heavy use by multiple users

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The perils of the fixed pricing model

□ It's here to stay; metered pricing rejected

□ Implications:

- Customer has no incentive to save bandwidth
- ISP cost depends on peak demand – 95/5 rule
- Reigning in bandwidth hogs is incompatible with Net Neutrality

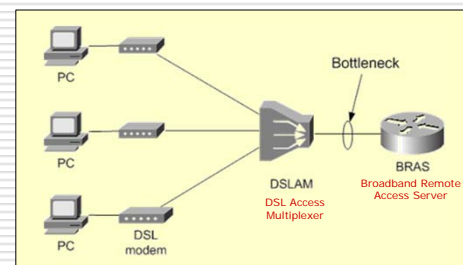
□ Must devise mechanisms that take ISPs out of the "traffic shaping" business

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DSLAM "last-mile" architecture



Traffic shaping done at BRAS

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Solution: Create a marketplace



- Recognize the two types of user traffic:
 - Reserved Traffic (RT)
 - For interactive browsing, VoIP, messaging, gaming, ...
 - Limited bandwidth; highly sensitive to response time
 - Fluid Traffic (FT)
 - P2P, Network backup, Netflix/software downloads, ...
 - Open-ended bandwidth; less sensitive to response time
- Create a marketplace:
 1. Give users rights to DSLAM bandwidth, and
 2. Let users trade RT/FT allocations over time

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The Marketplace



- Each user gets a fixed budget per epoch
 - Budget proportional to level of service
 - An epoch is a fixed number of time-slots, e.g., 1 day = 288 5-min slots
- Trade & Cap
 - User engages in a pure strategies game that yields a schedule for its RT bandwidth
 - User acquires as much FT bandwidth as its remaining budget would allow

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Trading Phase: Strategy Space



- Session:

An RT session is the sequence of slots during which an RT application is active
- Slack:

User may have flexibility in scheduling RT sessions; slack specifies the number of slots that an RT session is allowed to be shifted back/forth
- Strategy Space:

The set of all possible arrangements of RT sessions within allowable slack define the strategy space for a user

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Trading Phase: Cost Function



- Let x_{ik} be the bandwidth used in slot k by a chosen RT session schedule for user i .
- The cost incurred by user i is given by:

$$c_i = \sum_{k \in \text{slots}} x_{ik} \cdot U_k = \sum_{k \in \text{slots}} x_{ik} \left(\sum_{j \in \text{users}} x_{jk} \right)$$

- Cost of user i depends on the choices made by other users – hence the game!

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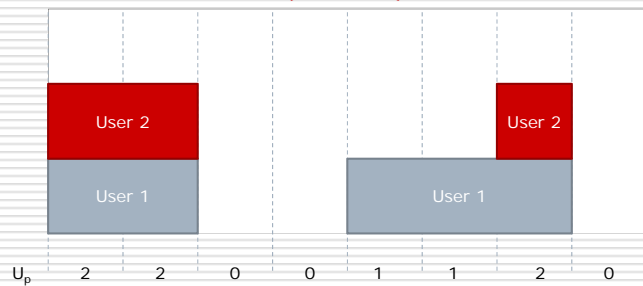
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Trading Phase: Illustration



$$\text{Cost}(\text{User 2}) = 6$$



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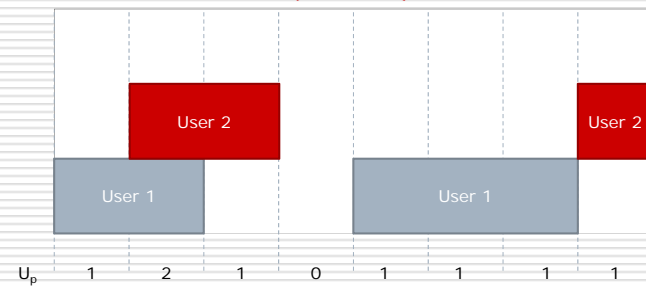
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Trading Phase: Illustration



$$\text{Cost}(\text{User 2}) = 4$$



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Trading Phase: Best Response



- BR of user i is a schedule of RT sessions that minimizes its cost c_i
- Computing BR is NP-hard, equivalent to solving a generalized knapsack problem
- Dynamic programming solution is pseudo-polynomial in the product of the number of sessions and number of slots
- Scales well for all practical settings – 100s of users and 100s of slots

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Trading Phase: Findings



- Provably converges to Nash Equilibrium, even in presence of constraints
- For n users, Price of Anarchy is n , but in practice below 2, especially for $n > 10$
- Experimentally, large reduction of peak utilization, even with small flexibility

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Capping Phase: Best Response



- BR of user i is to maximize total FT allocation

$$w_i = \sum_{k \in \text{slots}} w_{ik}$$

subject to the budget constraint

$$\sum_{k \in \text{slots}} w_{ik} \cdot \left(U_0 + \sum_{j \in \text{users}} w_{jk} \right) = B_i - c_i$$

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Capping Phase: Budget



- Let V be some desirable upper bound on the total traffic per slot
- The ISP sets a target capacity $C = V/R$, where $R \geq 1$ reflects its "resistance" to traffic
- The ISP allocates C in some proportion (e.g., equally) to all n users over all slots
- This constitutes the budget B assigned to a user over an epoch T

$$B = \frac{C}{n} \cdot T$$

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Capping Phase: Findings



- Locally computing BR is efficient using Lagrange Multipliers method
- Provably, converges to a unique global (social) optimum that maximizes the FT allocations of all users (thus could be done centrally by ISP)
- Experimentally, smoothes the aggregate RT+FT traffic to any desirable level controlled by the resistance parameter R

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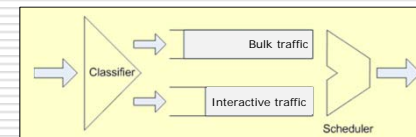
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Trade & Cap: Implementation



- On Client Side (e.g., DSL Modem):

- + Strategic agent to execute Trade & Cap
- + Operational service to profile, classify, and shape



- ISP Side (e.g., DSLAM or BRAS):

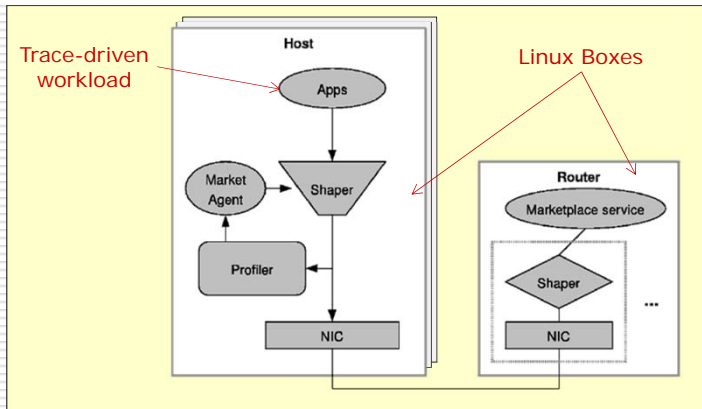
- + Support exchange between strategic agents
- + Enforce total traffic/slot/user from Trade & Cap

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Trade & Cap: Implementation



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Trade & Cap: Implementation notes

□ User Input:

- As simple as checking box to join marketplace, and as elaborate as micromanaging RT slacks
- May set a fraction of "budget" as insurance

□ Client-side Profiler:

- May be explicitly controlled by applications (or user settings)

□ Client-side Traffic Shaper:

- Work-conserving (not reservation based) Linux Hierarchical Token Bucket (HTB)
- Allows FT to use underutilized RT bandwidth

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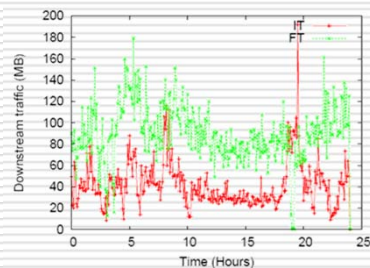
Experimental Evaluation

Workload

Derived from WAN traces of MAWI project†

- Identify users from volume and direction of flows to known ports (e.g., most traffic destined to port 80)
- Identify user RT sessions using thresholds on per-IP traffic intensities over time
- Slack introduced using various models (e.g., fixed, proportional, etc.)

Period	2009-03-31 00:00 – 2009-03-31 23:59
Total packets	1,551,089,845
TCP packets	1,194,409,653
UDP packets	4,321,852
Total TCP bytes (payload)	924,540,189,060



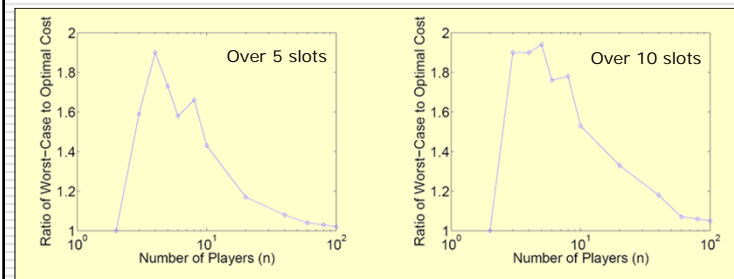
† Reported results are negatively impacted by less-than-ideal (atypical) trace.

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Trading Phase: Experimental PoA



Theoretical PoA is n but not in practice

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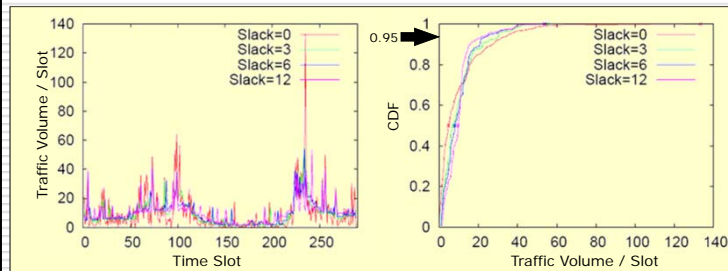
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Trading Phase: Smoothing effect



Value proposition to ISPs

Max Slack	Reduction in 95%
3	15%
6	24%
12	31%



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Trade & Cap: Flexibility pays off!



Value proposition to customers



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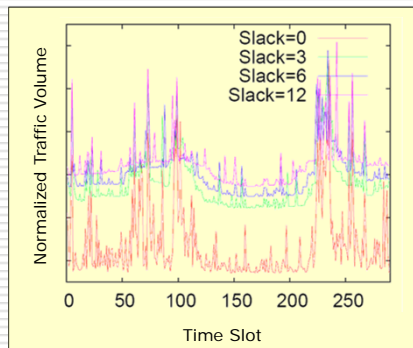
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Trade & Cap



A win-win for ISPs and customers



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Trade & Cap: Beyond DSLAMs



Trade & Cap is a *general* mechanism

It can be used to coordinate how a shared resource is used by selfish parties who are not subject to the "pay as you go" model – e.g., "fixed pricing"

Examples

- Coordinating consumption of "reserved" versus "fluid" (CPU/network) capacities of VMs sharing a single host
- Coordinating "reserved" versus "fluid" bandwidth utilization by multiple ISP customers (e.g., enterprises)

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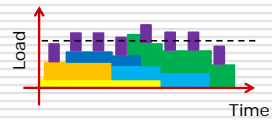
Selfish Resource Packing Problems



Shared bandwidth arbitration

- Trade & Cap

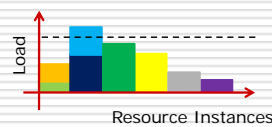
A temporal packing game



Cloud resource acquisition

- Colocation Games

A spatial packing game



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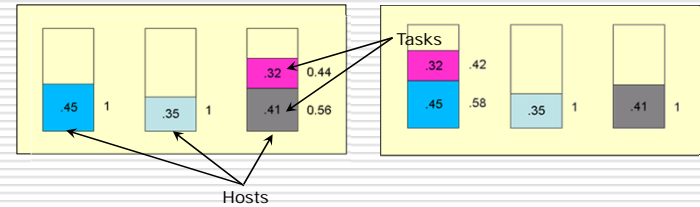
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Colocation Games



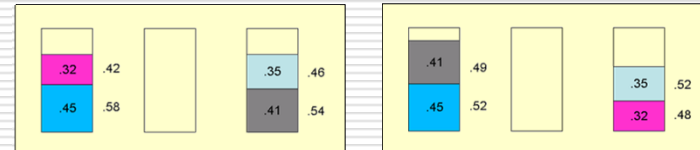
08:00 am / Amazon ← \$3

09:00 am / Amazon ← \$3



10:00 am / Amazon ← \$2

11:00 am / Amazon ← \$2

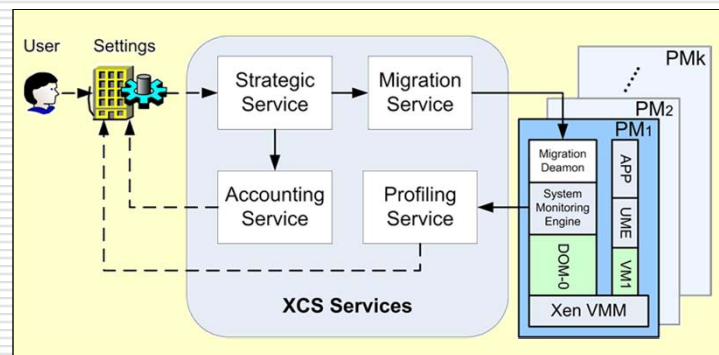


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CLOUDCOMMONS: Architecture

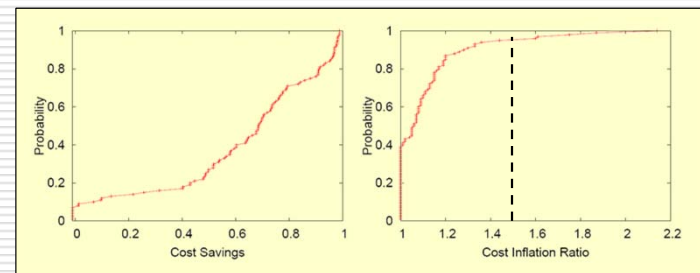


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CLOUDCOMMONS: Benefit to users



Multi-dimensional Planet-Lab trace-driven experiments
(Overheads/costs of all XCS services included)

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Conclusion

- In many settings, resource management can only be seen as a strategic game among rational peers
 - By setting up the right mechanism, one can ensure convergence and efficiency
 - New services are needed to support strategic and operational aspects of these mechanisms
- **Trade & Cap is an example of such mechanisms**
- It coordinates the shared use of a resource by trading in “rights to quality” for “volume”
 - It has been implemented in a last-mile setting as a proof of concept with very promising performance



Publications

- “netEmbed: A service for embedding distributed applications (Demo)”. Londono and Bestavros. *ACM/Usenix Middleware'07*.
- “netEmbed: A resource mapping service for distributed applications”. Londono and Bestavros. *IEEE/ACM IPDPS'08*.
- “Colocation games with application to distributed resource management”. Londono, Bestavros, and Teng. *USENIX HotCloud'09*.
- “Colocation as a Service: Strategic & operational cloud colocation services”. Ishakian, Sweha, Londono, and Bestavros. *IEEE NCA'10*.
- “Trade & Cap: A customer-managed system for trading bandwidth at a shared link”. Londono, Bestavros, and Laoutaris. *ACM/Usenix NetEcon'10*.

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