Economic and Incentives' Mechanisms for All-Win Overlay Traffic Management

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Outline

- Introduction to economic mechanisms
- Economic management of overlay traffic
  - Project SmoothIT
- Concluding remarks

Introduction to economic mechanisms

Win-Win

Why Charge for Telecommunication Services ?

- In order for the Network/Service Provider to:
  - Recover costs
  - Make profits and save capital for future expansion
  - Control the system, by providing the right incentives for rational usage:
    - Similarly to charging for street-parking in a city
  - Obtain information from users:
    - examples: special service packages
      → their adoption is indicative of user's preferences

Terminology

- price: related to a “service” unit
  - E.g. €/Mbyte of €/callminute
- tariff: charge structure
  - more general form of charging: e.g. *a+px*
  - *control mechanism*
- charge: total amount that must be paid

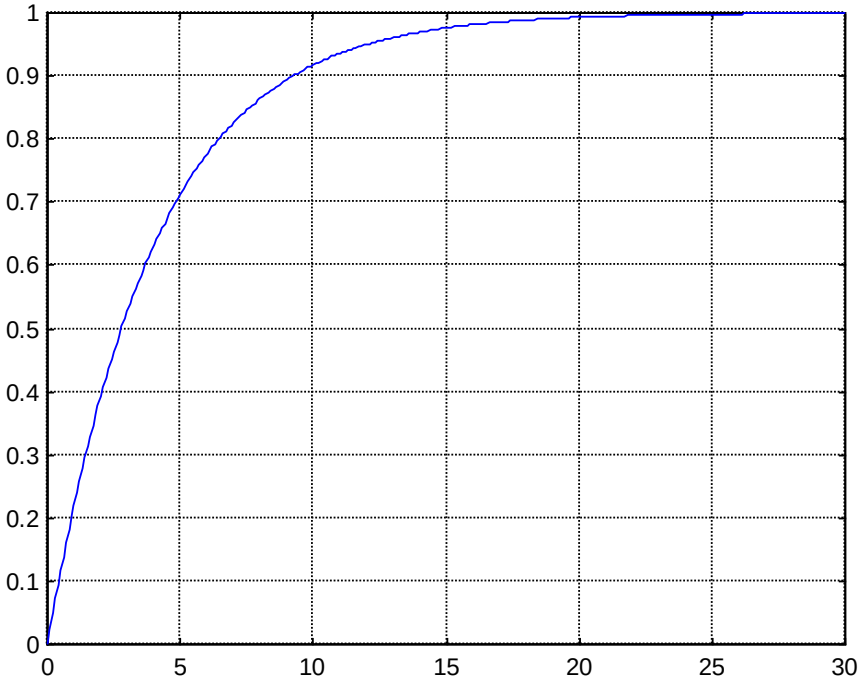
User Utility Function

- A user has to select the quantities
  $\boldsymbol{z} = (z_1,..,z_n)$ of n goods.
  - A choice $\boldsymbol{z}$ is preferred to $\boldsymbol{z}$' iff $U(\boldsymbol{z}) > U(\boldsymbol{z}')$

- $U(\boldsymbol{z})$ = user's benefit/satisfaction from $\boldsymbol{z}$, in €, CHF, $…
  - Willingness-to-pay for $\boldsymbol{z}$
  - Benefit from resale

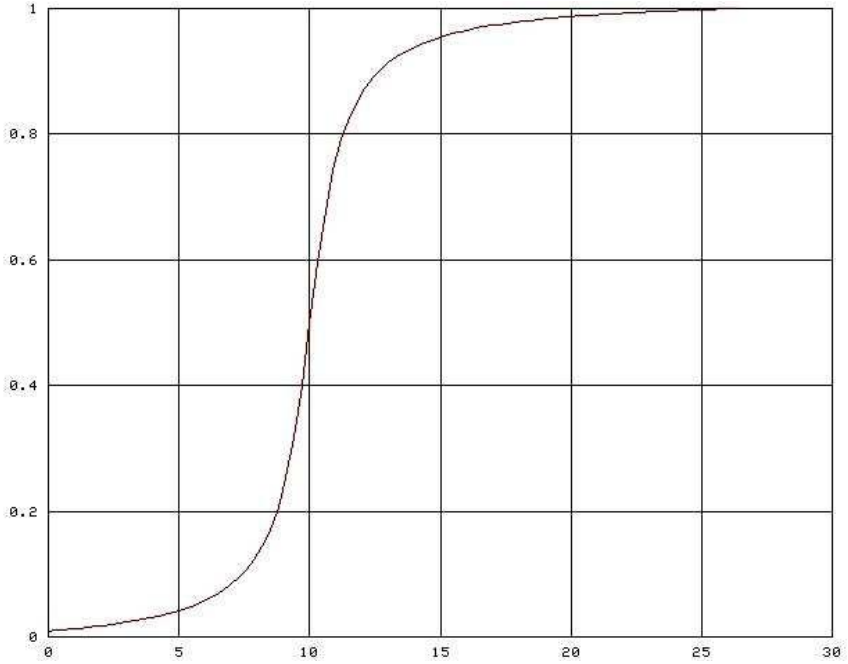
- Net benefit selection criterion: $\text{Max}_z\{U(\boldsymbol{z}) - c(\boldsymbol{z})\}$

Utility Functions for Bandwidth



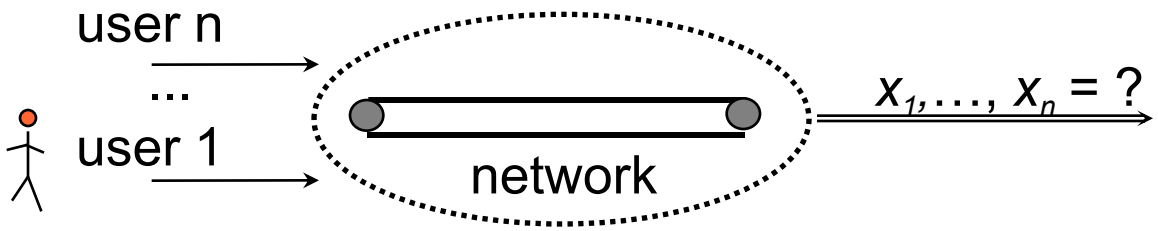
Elastic service

Guaranteed service



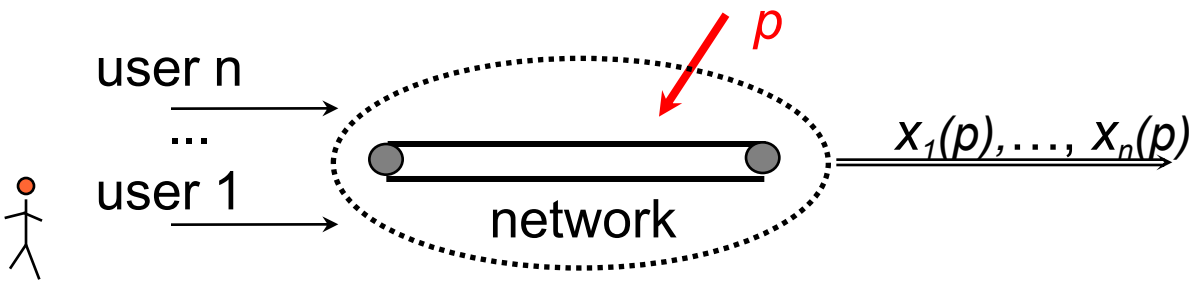
Optimal Bandwidth Allocation

- The available quantity of resource is finite
- Users are pursuing their own benefit
  - The provider does not know the user utility functions
- How can the total benefit of users be maximized?
  - Even distribution of the capacity is not economically efficient in general



Pricing as a control mechanism

- Use pricing as an internal control mechanism
  - Provider sells bandwidth at a price p per Mbps
  - Given this price, each user i selects amount $x_i(p)$ purchased
  - There exists an equilibrium price p for which all user choices "collectively" form the socially optimum allocation



How much should I ask if the price is p ?

More formally (I)

- Single link, capacity C shared by multiple users
- Social welfare maximization problem:

$$\max_{\{x_i\}} \sum_i u_i(x_i) \quad s.t. \quad \sum_i x_i \le C \quad (1)$$

- Mathematical solution → Maximize the Lagrangian

$$\max_{\{x_i\}} L(\lambda, \{x_i\}) = \sum_i u_i(x_i) - \lambda(\sum_i x_i - C)$$

The optimal point of (1) is characterized by $\lambda, \{x_i\}$ for which:

$$\frac{\partial u_i}{\partial x_i} = \lambda, \sum_i x_i = C$$

More formally (II)

- Distributed solution of the problem with economic mechanism → use a price p
- Each user solves its own problem: $\frac{\partial u_i}{\partial x_i} = p$
- If $\sum_i x_i \neq C$ then update price by means of iterative tattonement process → Under general market conditions the market price p will converge to λ
- Approach applicable to networks

Incentives and Mechanism Design

- *... incentive constraints should be considered coequally with resource constraints in the formulation of the economic problem.*

  R.Myerson, Nobel Prize in Economic Sciences, 2007

- Mechanisms can help us:
  attain an outcome in a complicated optimization problem, in a distributed way
  - *The "engineering" side of economic theory.*

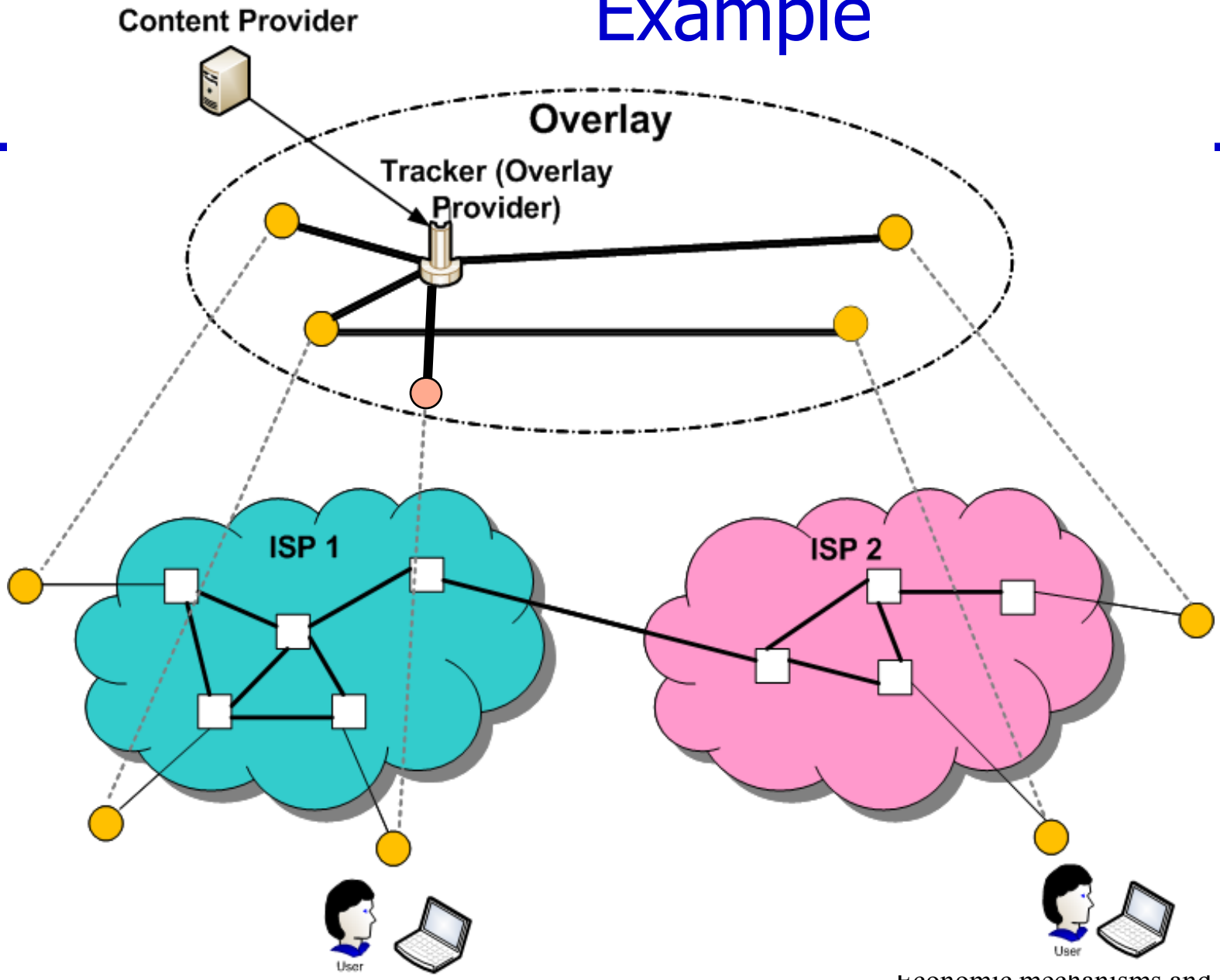
    E.Maskin, Nobel Prize in Economic Sciences, 2007

Economic management of overlay traffic

The Internet Ecosystem

- Many players acting simultaneously
  - Customers/Users
  - Providers
    - ISPs
    - Overlay application providers
    - Over-The-Top providers
    - Content providers
    - ...

Example


Content Provider
Overlay
Tracker (Overlay Provider)
ISP 1
ISP 2
User
User

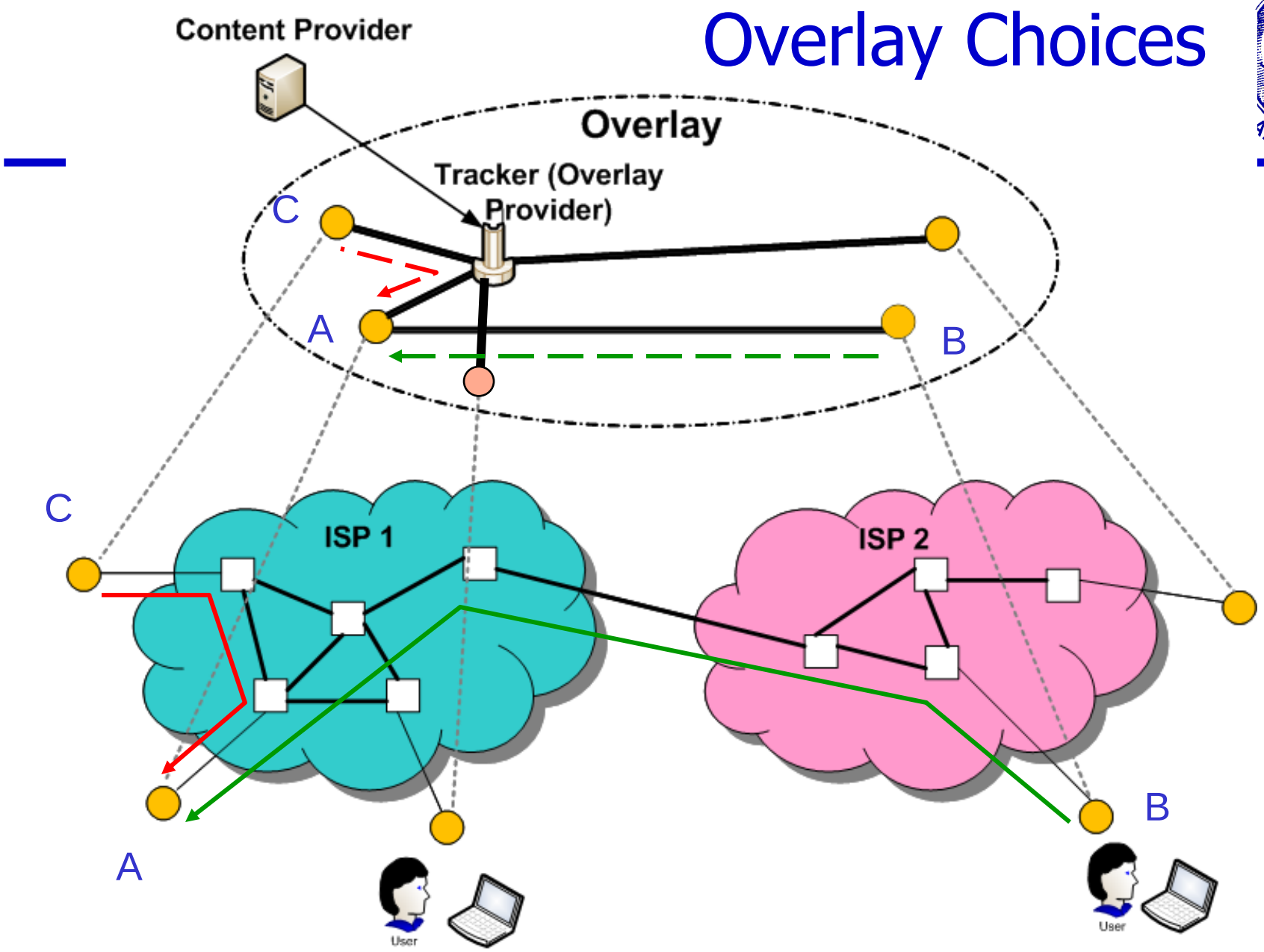
Overlays & Information asymmetry

- Peer-to-Peer (P2P) and other overlays generate significant traffic volumes; e.g. BitTorrent

- Overlays built independently of physical network
  - Underlay *topology* not known to overlay
  - Overlay *requirements* not known to underlay

➔ Non-optimized overlay traffic inserted in the underlay:
  - Higher costs in the underlay for the ISP
  - Lower quality in the overlay for application provider & users

Overlay Choices



Tussles in Internet

- Overlay and underlay engaged in a tussle

➔ Self-interested players with:

  - conflicting interests
    and
  - substitute or complementary functionalities

- Due to tussles it is only meaningful to aim for equilibrium operating points
  - not for global optima of the system

Target: All-Win Situation

- Conventional traffic management not applicable
  - Aims at achieving a global optimum
    1. for a single criterion;
    2. by a central entity
       - with full information

➔ Target: Manage traffic beneficially for all players

The FP7-ICT Project *SmoothIT*

***S**imple Economic **M**anagement Approaches **o**f **O**verlay **T**raffic in **H**eterogeneous **I**nternet **T**opologies*

- Main objective: To optimize overlay traffic mutually beneficially for all ISP, user, application provider
  - File-sharing and Video-on-Demand
- Approach: Economic Traffic Management (ETM), with mechanisms based on the incentives of players

Optimization in Overlays

- Overlays already include mechanisms to optimizate user performance
  - e.g. tit-for-tat in BitTorrent

- These perform suboptimally:
  1. due to incomplete information (→ asymmetry)
  2. conflict with ISP's incentives

ETM Mechanisms (I)

- Are based on addressing economic incentives
  - providers' revenue/cost etc.
  - application/user performance,

  which are promoted compatibly for all players

- Exploit the existing overlay structure and mechanisms involving choices;
  e.g. overlay neighbor selection
  - Are highly distributed and scalable

ETM Mechanisms (II)

- Stimulate information sharing among players

- ISP affect users' individually optimal choices and overlay traffic patterns desirably by:
  1. providing users with extra underlay information
     - locality promotion
  2. offering extra resources in the overlay to "help" local users

ETM Mechanisms (III)

1. BGP-based Locality Promotion (BGP-Loc)
   - A server provides proximity-related information, employed optionally by the querying peer

2. Insertion of ISP-owned Peers (IoP) in swarms
   - A resourceful entity enhancing both user performance and traffic locality within an ISP

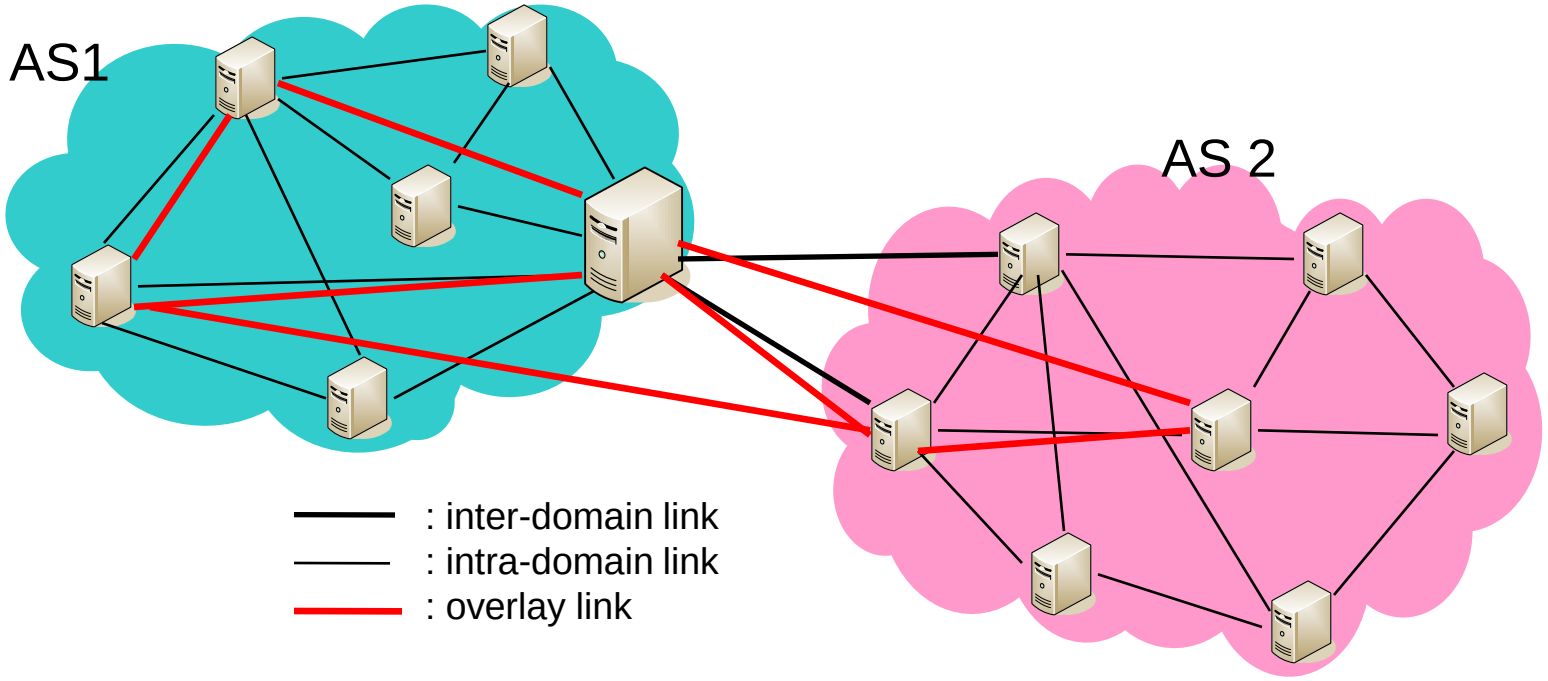
3. Promotion of Highly Active Peers (HAP)
   - ISP boosts regular peers' capacity in order to serve as IoPs

ISP-owned Peer (IoP - I)

- Resourceful entity that acts as *overlay peer*:
  - Belongs to and is controlled by the ISP
  - Participates actively in the overlay
  - Exploits self-organizing mechanism , e.g.“tit-for-tat” (t4t)
  - Act as *non-intercepting* cache
  - Has *no* content initially → acquires the content gradually
  - Can be set to serve only local peers: unchoking policy

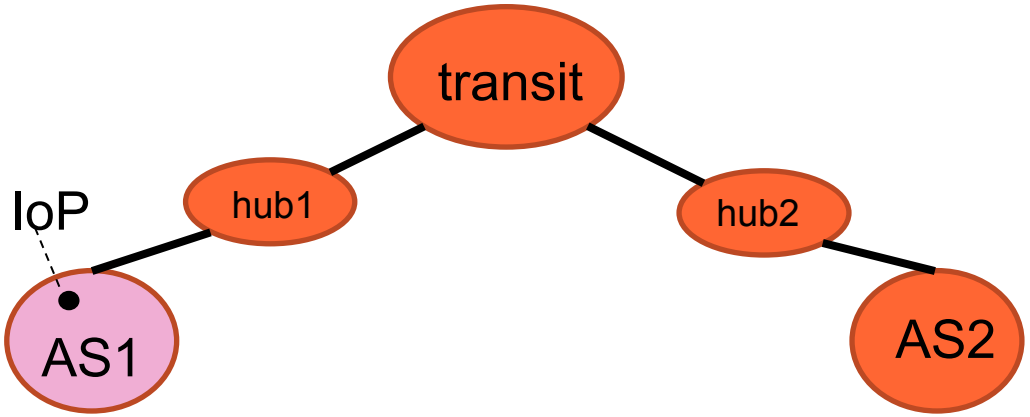
ISP-owned Peer (II)

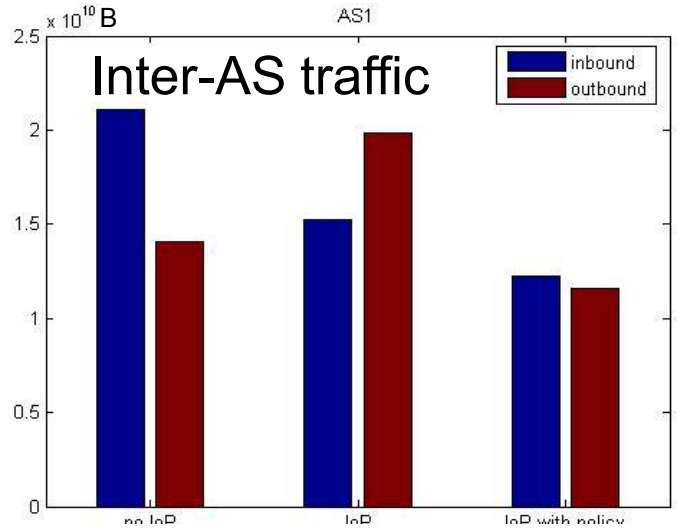
- Not an intercepting cache
- Not a gateway peer

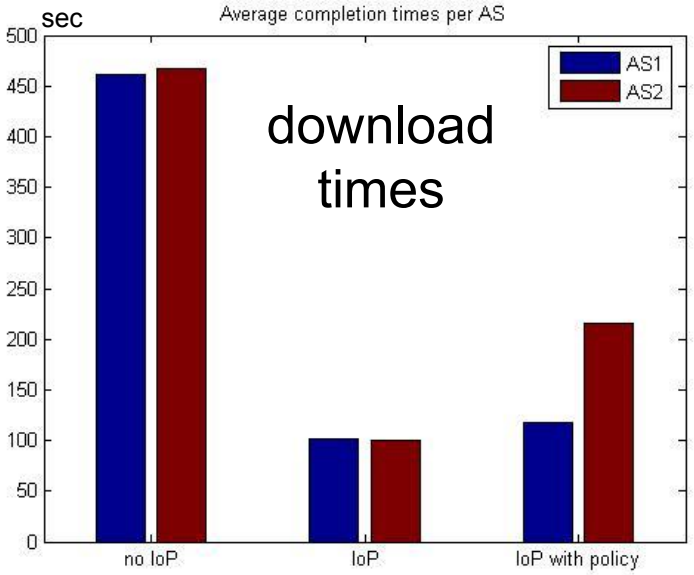


Evaluation of the IoP Insertion

- Plain IoP:
  - Significant improvement in users' performance
  - Inbound traffic reduction / Outbound traffic increase
    - Further impact under the unchoking policy

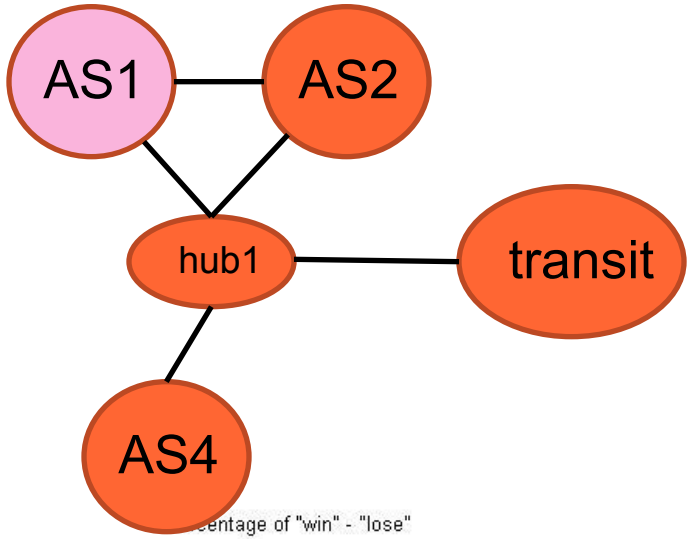


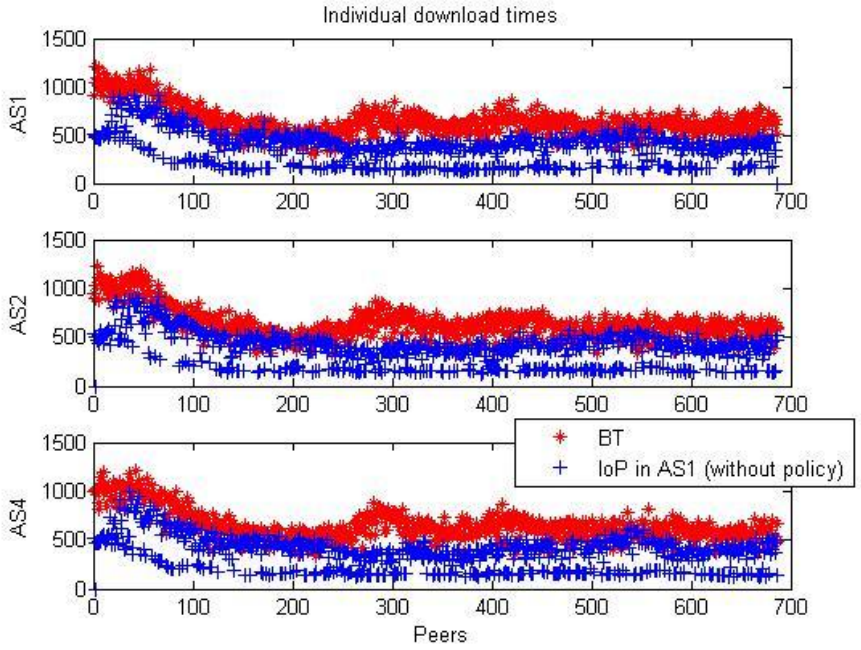


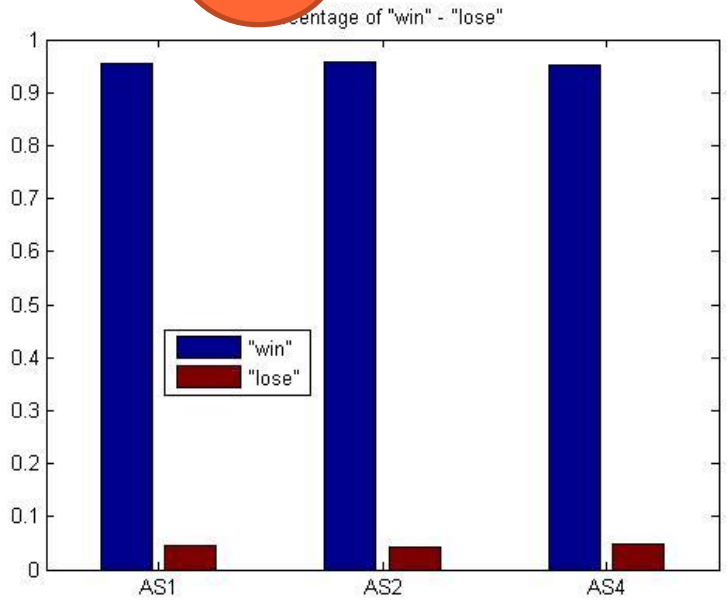


Evaluation of the IoP – Individual User

- 3 AS-topology
- Performance improvement for 95% of the users







Concluding remarks

Main Conclusions

- ETM can lead to All-Win
  - Existing overlay optimization can benefit from ETM
- Locality reduces costly inter-domain traffic
  - … but does not always lead to All-Win
  - possible performance deteriotation
- Use of resourceful entities is often effective

Final Remarks

- No ETM approach can fit all cases/applications
- ETM should not affect adversely other applications
- All-Win should be studied with special modeling and assessment methodologies

Thank you for your attention!