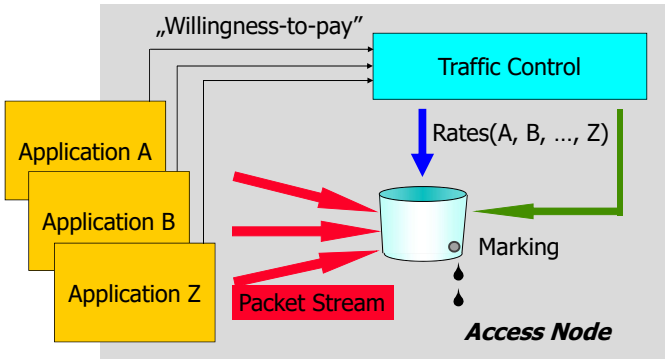
Part 5: Internet Economics

- Internet Economics
  - Basics and Definitions
    - Architecture
  - Utility and Externalities
  - Pricing and Charging
    - Expected Capacity
    - Smart Market
    - Cumulus Pricing Scheme
  - Economic Traffic Management

Why is There a Need for Charging?

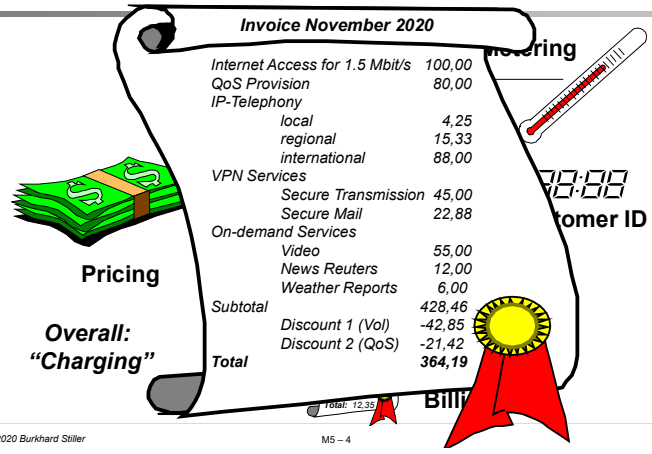
- Charging, accounting, and pricing helps Internet Service Providers (ISP) to:
  - Improve network performance,
  - Provide fair QoS provision,
  - Produce user satisfaction,
  - Create revenue, and
  - Make profits.
- Mechanisms for charging, accounting, and pricing have to be:
  - User-incentive compatible,
  - Simple and understandable, and
  - Efficiently implementable and transparent.

Generic Architecture of an Access Nodes

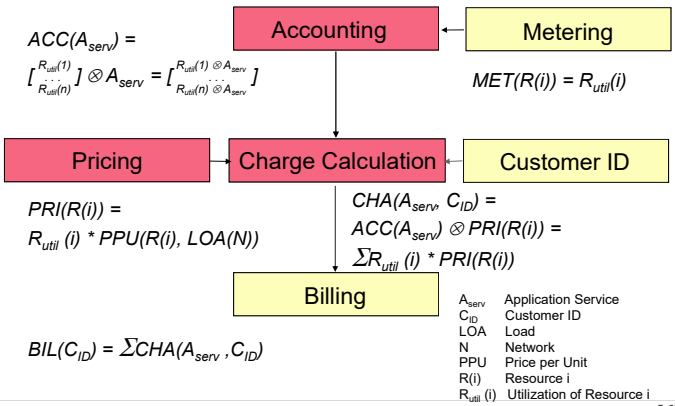


- Fairness is based on willingness-to-pay.

Architectural Components



Formal Architecture



Basic Definitions

- Metering: Determining the particular utilization of resources within an end-system and the network (monitoring).
- Accounting: Acquiring and summarizing of information (accounting records) in relation to a customer's service utilization, expressed in metered resource consumption, *e.g.*, for the end-system, applications, calls, or connections.
- Pricing (Tariffing): (Regulated) specification of prices for goods, specifically, for networking resources and services.
- Charging: Completing the calculation of a price for given accounting records and its consolidation into charging records, while mapping technical values into monetary units.
- Billing: Collecting charging records, summarizing their charging content, and delivering a bill including an optional list of detailed charges to a user.

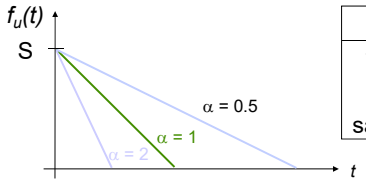
Traffic Management – Utility

- Utility functions are required to find an optimal resource allocation, while maximizing the utilization of this resource.
  - Network or service users are modeled by their required degree of satisfaction or utility:
    - User's value of certain QoS over price.
    - Means of distinguishing diverse performance.
  - f_u: QoS → Utility
- Mathematical representations of utility desirable.
  - Expression of preferences can be coded.
  - Problem: "Required" properties of f_u not always existent.
  - Mechanisms are relevant, although algorithms are difficult.

Utility Functions – Example (1)

Based on [Kesh97]

- File transfer example:
  - $f_u(t) = S - \alpha t$
    - t: transfer time of the file
    - S: satisfaction in case of infinitively fast transfer
    - α: rate at which the utility decreases over time
  - $t > S/\alpha$: negative utility: too long lasting transfer time.



Example File Size: 1 MByte

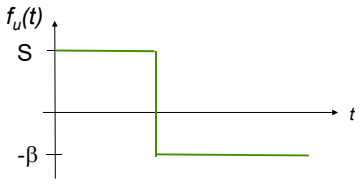
Utility	Time	Data rate
very well	1 s	8 Mbit/s
good	10 s	800 kbit/s
satisfactory	60 s	133 kbit/s

α "proportional" to price.

Utility Functions – Examples (2)

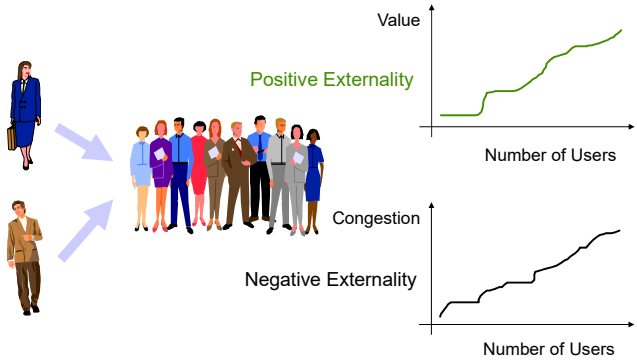
Based on [Kesh97]

- Videoconferencing example:
  - $f_u(t) = S$ for $t < D$ and $-\beta$ for $t \geq D$
    - t: end-to-end delay for a packet
    - D: delay deadline
    - S: satisfaction for a packet meeting the deadline
    - β: cost for missing the deadline
  - Penalty reflects the payment for a missed deadline.



Network Externalities (1)

- Where is the critical mass?

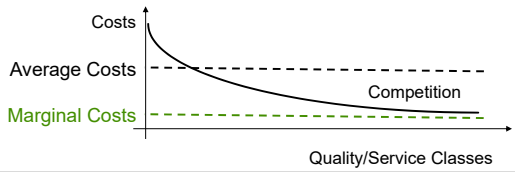


Network Externalities (2)

- In addition to pure economic policies, methods are required to deal with congestion externalities:
  - Users benefit from shared resources' usage, but ignore costs they impose on other users, *e.g.*, in terms of delays or packet losses.
- Clearly, congestion determines a negative externality.
  - A positive externality would be, *e.g.*, "a pleasure to watch flowers in a neighbor's garden" [Vari96].
  - However, congestion externalities do not set a market!
  - Today, every network user may consume services without worrying about other users.
  - Pareto efficiency may not be achieved without legal acts.
  - Tragedy of the commons: Overgrazing a meadow ...

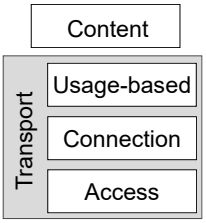
Pricing Models

- Quality supports service differentiation!
- Quality increases service value!
- Congestion control influences user behavior.
  - Make users to shift traffic to other links or
  - Make users to pay for the scarce resource.
- Pricing is a source of revenue for service providers.



Pricing Components

- Telecommunication pricing includes components:
  - Access: normally monthly flat-fee, *e.g.*, depending on b/w.
  - Connection: *e.g.*, per-call, per-connection, per-reservation.
  - Usage per connection: *e.g.*, time, volume, QoS (determining the actual usage based on economic principles).
- Independent of transport services a content price may be introduced:
  - Omitted (phone, fax, e-mail),
  - Billed separately (on-line services), or
  - Integrated (*e.g.*, 1-900 numbers).
- Network externalities play a significant role during congestion.



Usage-based Charging

- Charging depending "on usage".
  - Requires resource allocation mechanisms for managing distinguished resources.
  - Measurement and accounting infrastructure required.
- Advantages:
  - Allows for service differentiation based on valuation.
  - Supports the goal of network efficiency and economic efficiency (Pareto efficiency), congestion avoidance.
- Drawbacks:
  - Measurement and accounting for each activity, resource.
  - Difficult projection of financial budgets.
  - User reaction on price-QoS ratio unknown.

Concerns with Usage-based Approaches

- Any overhead must be limited:
  - Protocols: *e.g.*, between service users, the provider.
  - Memory: especially in routers.
  - Processing: especially in routers, but also in end-systems.
- The approach should not eat up its gain.
  - Does it cost more than simply over-provisioning?
- The approach should not bother users.
- The approach should provide a choice of pricing models for inter-operating providers (peering).
- The approach should not be limited to a single network technology.

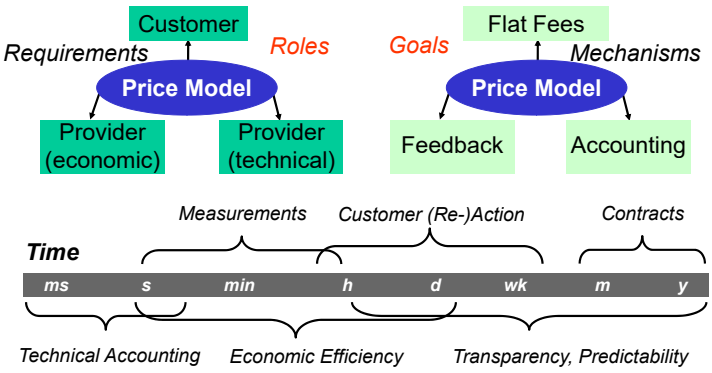
Flat Fees

- Fixed fees for IP access, independent of:
  - Bandwidth utilization, Quality-of-Service, or congestion.
  - Transmitted information or users' valuation.
- Advantages:
  - Simplicity for user and provider, minimal effort.
  - Reduced risk and a simple financial budget.
- Drawbacks:
  - Appearance of unintended congestion.
  - No incentives for resource usage.
  - Assignment of bandwidth by time, not by price.
  - Bandwidth assignment based on patience, not (social) valuation.

Over-provisioning

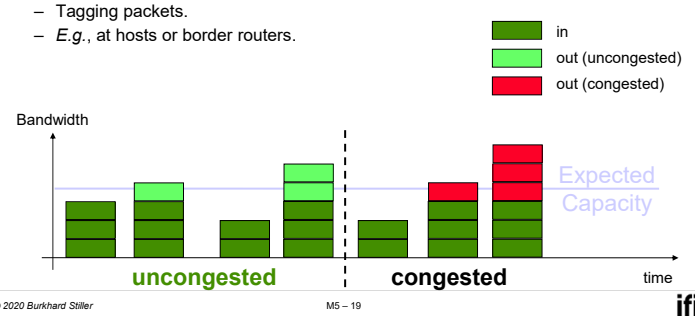
- Provisioning of "sufficient" bandwidth.
  - Possible due to small/decreasing cost.
  - Regional cost differences.
  - Still, decreasing cost.
- Advantage:
  - Larger bandwidth for the same amount of money.
- Drawback:
  - There is no natural limit for bandwidth usage.
  - Cost are not limited by an upper boundary.
  - No traffic control in place, lack of sufficient real-time support.

Time-scale "Trilemma" of Internet Pricing



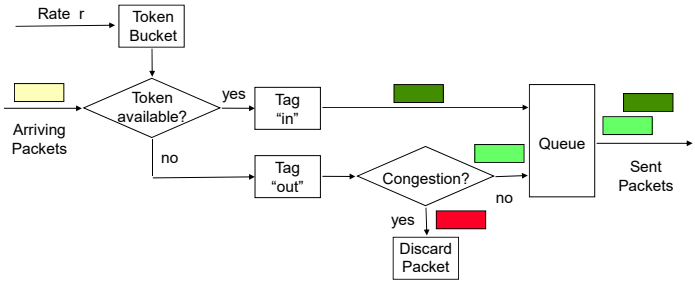
Pricing Expected Capacity (1)

- Idea: Negotiation of expected capacity:
  - Free usage or restricted usage during congestion.
  - Handles total elapsed transfer time and data sizes.
- Mechanism:
  - Tagging packets.
  - *E.g.*, at hosts or border routers.



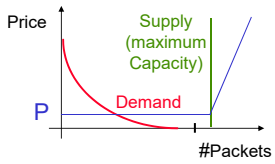
Pricing Expected Capacity (2)

- Tagging algorithm:
  - Token generation, tagging, and packet discarding.
  - Token bucket defines burstiness, *e.g.*, 2 kbit every 10 s.

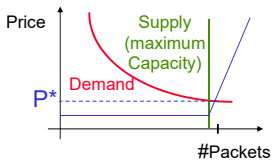


Smart Market

- Economical fair approach for networking:
  - Bids per packet are used to decide who goes.
  - Gain at capacity bottlenecks leads to extension detection.
  - Packet-based implementation with drawbacks.



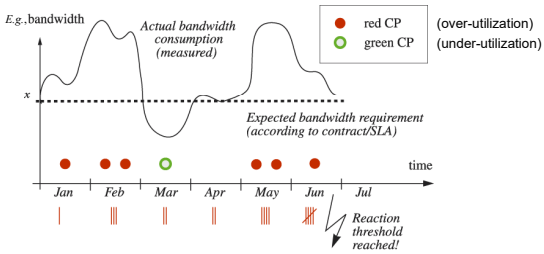
P: Base price, if #packets ≤ max. capacity.



P*: Auction price, if #packets > max. capacity.

Cumulus Pricing Scheme (CPS)

- ISP offers price function on resource x: $p(x) = \lambda / x^{1/2}$.
- Customer states resource requirement x over period t.



- Cumulus Point (CP) Rule ⇒ Thresholds.
- Reaction Rule ⇒ Accumulation.

} Economic feedback signals.

CPS – Formal Definition

- Monthly over/underutilization with respect to resource statement x: $\Delta_i = \Delta(t_i)$

i.e., $$\Delta_i = \int_{t_{i-1}}^{t_i} (V(t) - x)\,dt = \int_{t_{i-1}}^{t_i} V(t)\,dt - x(t_i - t_{i-1})$$

- t_i describes end of measurement period i.
- θ_{c_i} defines thresholds for CP assignments.

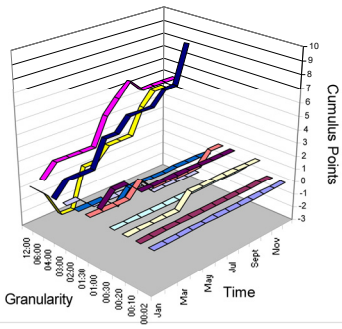
- CPs assigned: $0 \le \theta_{c_i} \le \Delta_i < \theta_{c_i+1}$ or $\theta_{c_i-1} < \Delta_i \le \theta_{c_i} \le 0$

- Reaction threshold: Θ imbalanced contract: $|\Gamma_n| \ge \Theta$

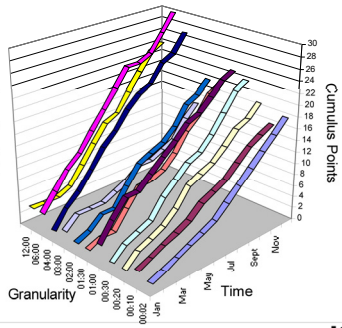
CPS Stability: Different Sampling Intervals

- CP assignments of real-world network traffic:

For correct traffic estimation x.



For 10% underestimation of x.



Economic Traffic Management

Future Internet

- Use of economic mechanisms for controlling, managing network traffic of overlays is termed:

  ⇨ **Economic Traffic Management (ETM)**

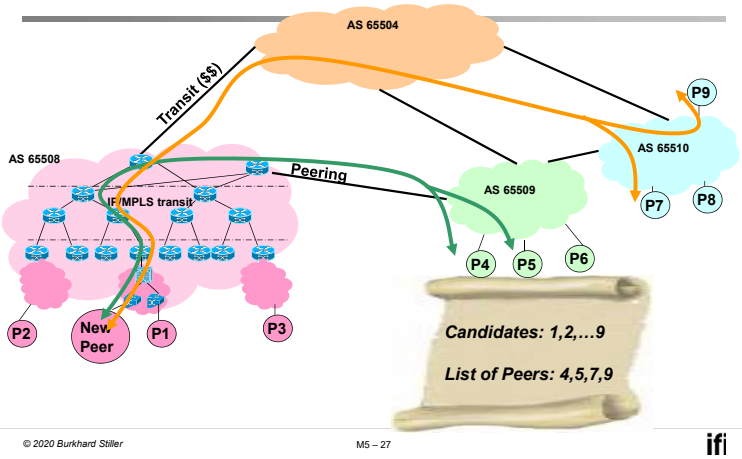
- SmoothIT results show that such mechanisms do have the important property of scalability and effectiveness!
  - Situation-dependent ETMs lead to a more efficient network operation
  - ETMs generate a higher value (QoE) for its customers.

- In managing the traffic created and routed through their networks, today's ISPs are offered by SmoothIT methodologies suitable for modern traffic/service profiles
  - *E.g.*, peer-to-peer traffic is treated according to ETM approaches.
  - Applicable to traffic of different P2P applications

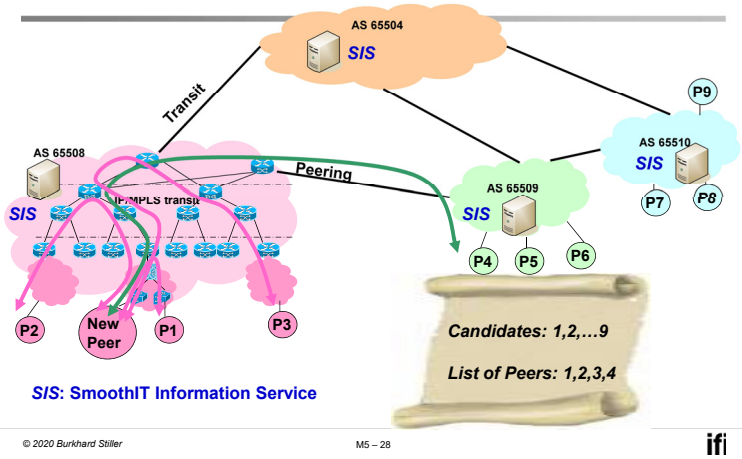
Triple Win

- Management of **overlay networks** based on a collaboration between the overlay provider and the network (underlay) provider in support of the user
  - Cost and investment recovery for operators
- Incentives for operators
  - Monetary: reduce overlay traffic and inter-domain traffic
  - Traffic management: less congested links, better performance
  - Reputation: keep customers, distinguish from other operators
- Incentives for overlay providers
  - Performance: Active role in traffic mgmt increases service quality
  - Reputation: increased user base due to better performing services
- Incentives for user
  - Performance: Increased service quality, *e.g.*, reliability, RTT, BW
  - Monetary: lower price for network access

Example: Locality-unaware Overlay

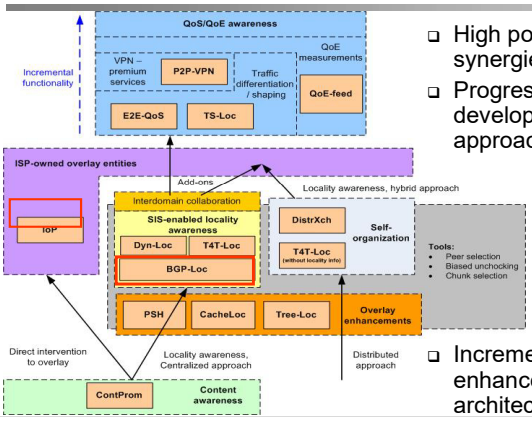


Example: Locality-aware Overlay



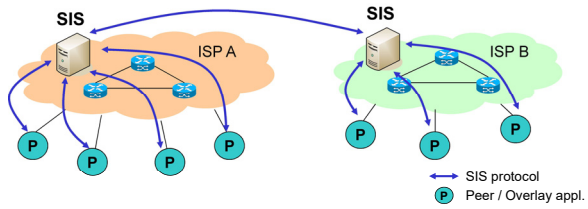
***SIS*: SmoothIT Information Service**

ETM Classification and Synergies



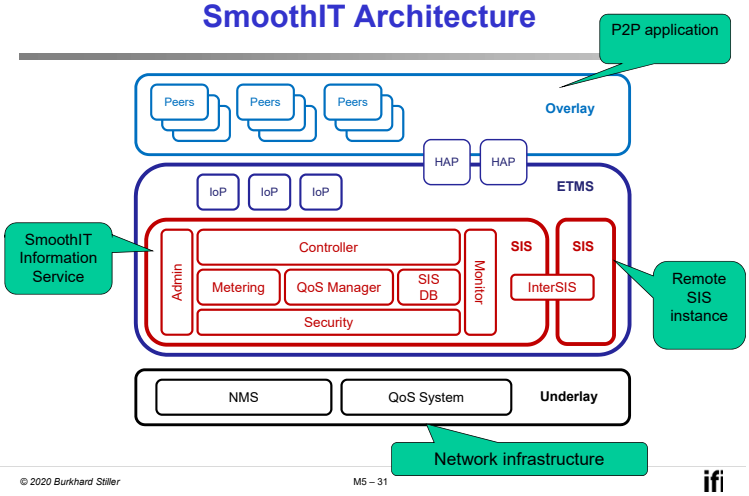
- High potential for synergies
- Progressive development of approaches possible
- Incremental enhancement of architecture possible

SmoothIT Information Service (SIS)



- Deployment of SIS components in the ISPs' network
  - To convey information between overlay and underlay
- Client-Server architecture
- Overlay applications interact with SIS in order to select „better" peers
  - Reducing costs of ISPs
  - Improving QoE of users

SmoothIT Architecture



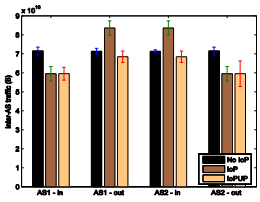
Sample ETM: ISP-owned Peers (IoP)

- *Motivation*: Sole locality may not improve peers' performance. Exploiting overlay functioning localizes traffic and achieves Win-Win
- *Approach*: Insert an ISP-owned peer (overlay entity) provisioned with higher access capacity
- *Impact*: Improvement of peers' performance and reduction of inbound traffic
- *Innovation*: Transparency, no interception required. Variety of policies

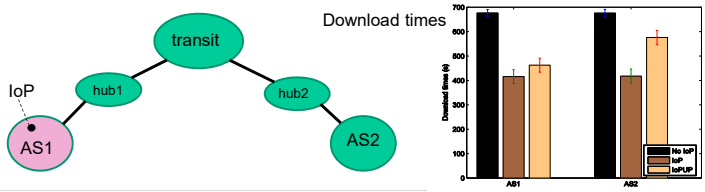
Evaluation of IoP (1)

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

Inter-AS traffic

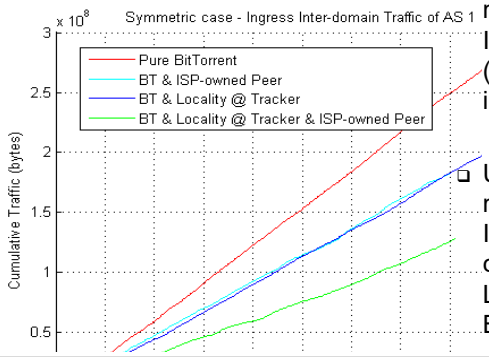


Download times



Inbound Inter-domain Traffic for AS 1

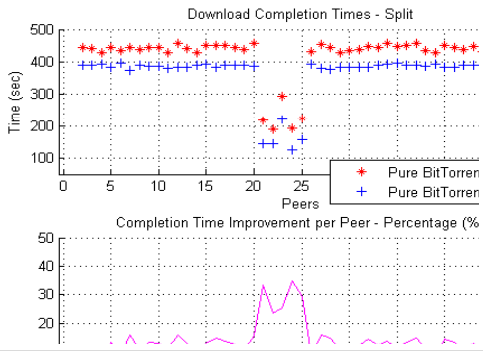
- Symmetric, All-together



- Up to 35% traffic reduction when IoP is inserted (either in BT or in BT&LA)
- Up to 50% traffic reduction when IoP insertion is combined with LA vs. original BT

End-Users' Download Times

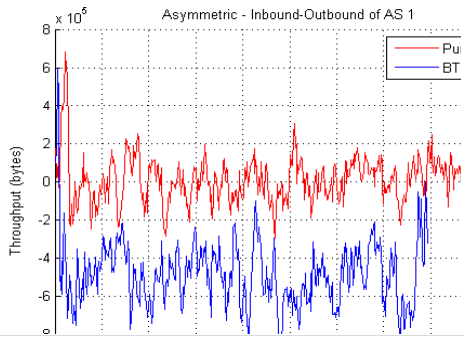
- Symmetric, Split



- Significant improvement especially for peers that enter the swarm later, when IoP has already turned into a seed

Instantaneous Difference between Inbound and Outbound Traffic of AS 1

- Symmetric, All-together



- Consider an interconnection charging scheme that takes into account the ***difference*** of inbound-outbound

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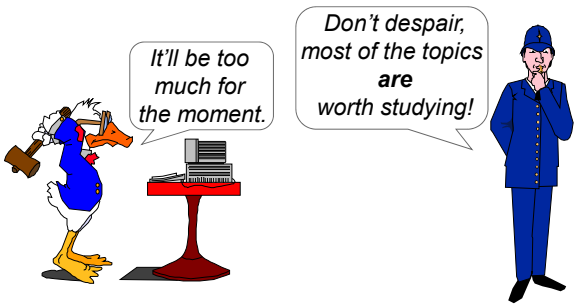
Many new slides, changes, updates, and preparations for most parts of this lecture have been performed, while still an amount of material has been inherited from various books and other lectures as generally referenced with the respective module or listed separately.

Good Bye Now!

- Thanks for joining the lecture and good luck for all of your upcoming exams in the future. CU!