Charging and Accounting Technologies for the Internet

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Overview

- Introduction
  - Roles, Internet, ISPs, and Terminology
- Accounting Technologies and Models
  - Network Management and AAA
  - RADIUS, Diameter, and SLAs
- Charging Approaches
  - Basics: Utility and Incentives
  - Pricing and Architecture
  - Principles: Usage-based, Flat Fee, Over-provisioning
  - Related Approaches: Expected Capacity and Smart Market
  - Feasibility Problem and Cumulus Pricing Scheme
- Conclusions
  - Revisited Requirements and Next Steps

Introduction

The Need for Charging and Accounting

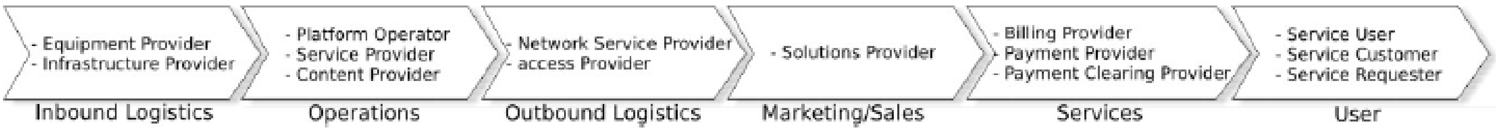
- Charging, accounting, and pricing helps Internet Service Providers (ISP) to:
  - Improve network performance
  - Provide fair QoS provision
  - Produce user satisfaction
  - Create revenue
  - Make profits.

- Mechanisms for charging, accounting, and pricing have to be:
  - User-incentive compatible,
  - Simple and understandable, and
  - Efficiently implementable and transparent.

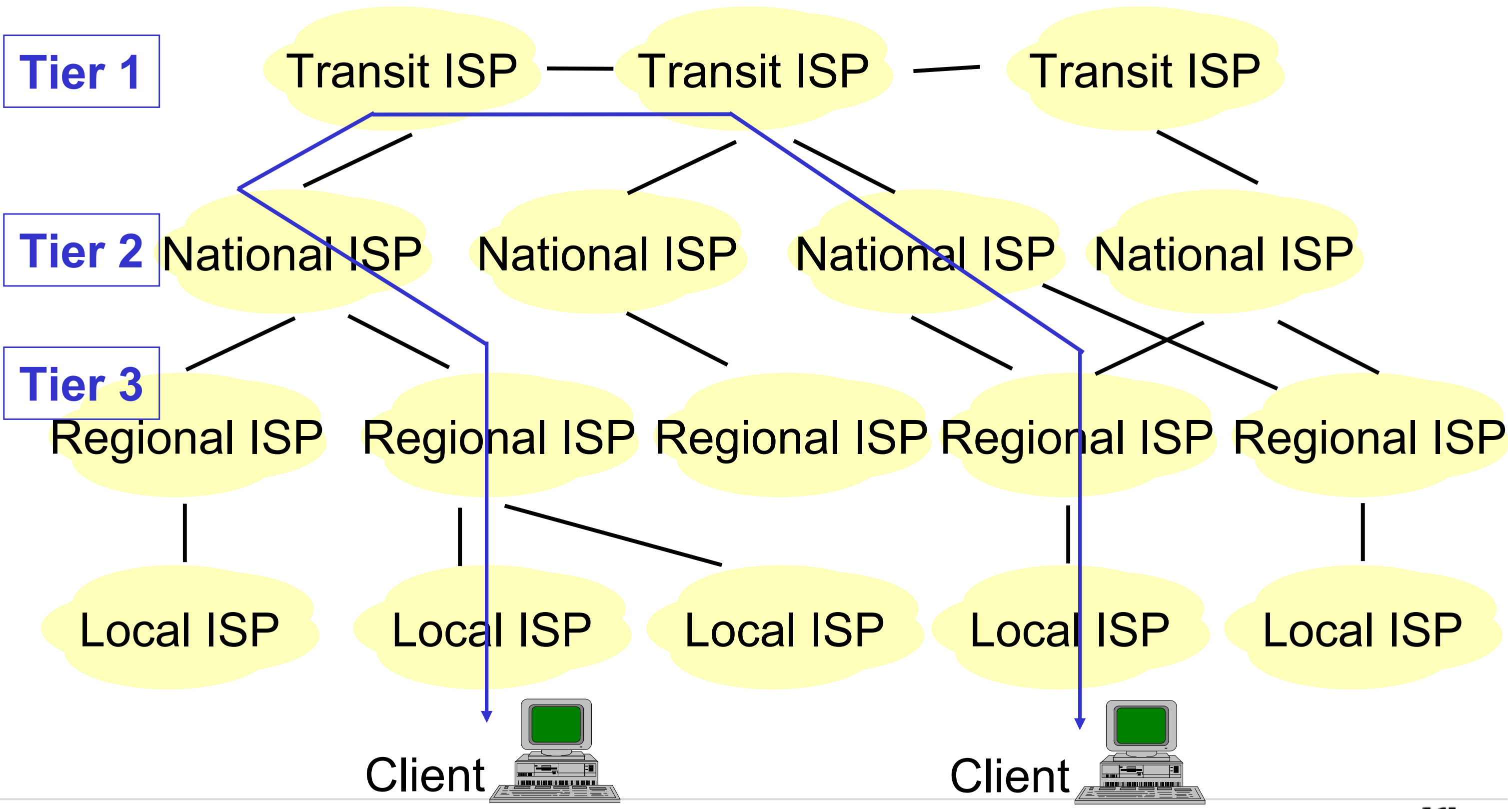
Roles and Mapping

- Service provisioning model
  - Service provider
  - Service user
  - Resource provider

- Specific instantations in assumed circumstances
  - Based on Porter's approach (1985)
  - Business Role to Value Chain Mapping



The Hierarchical Internet Structure

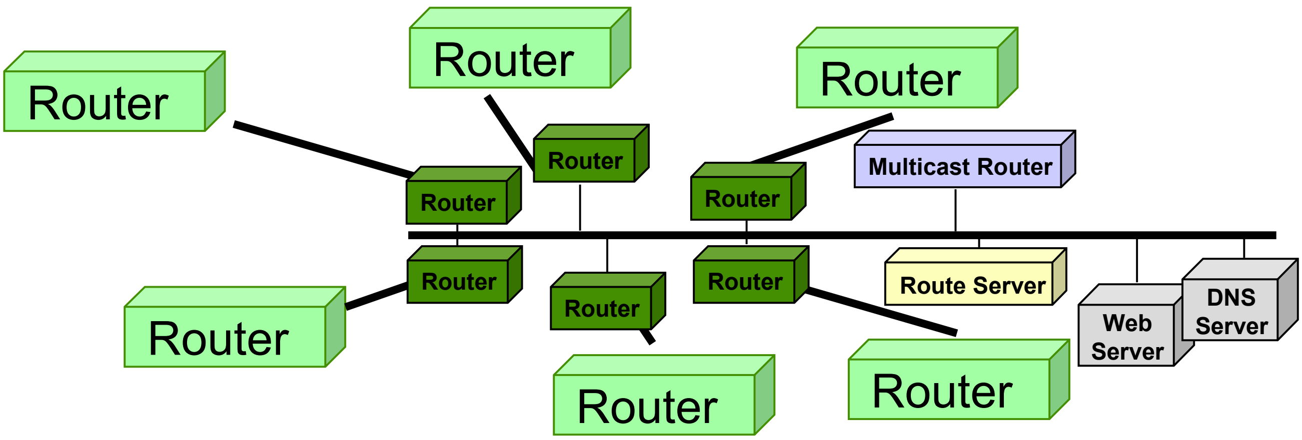


Interconnection Architectures

- The Internet's topology is distributed
  - Closer is cheaper (economic):
    Electromagnetic power varies in accordance with the distance.
  - Closer is faster (technical, QoS perception):
    Close distances between sender and receiver minimizes the delay.
  - Closer is more efficient (technical, economic):
    Faster protocol operation.
- Implication: Localization of data traffic.
  - Distinct and measurable advantages, physically short and cheaper.
- Considerations of locality:
  - Exchange model in terms of co-location model
  - Network Acces Points (NAP).

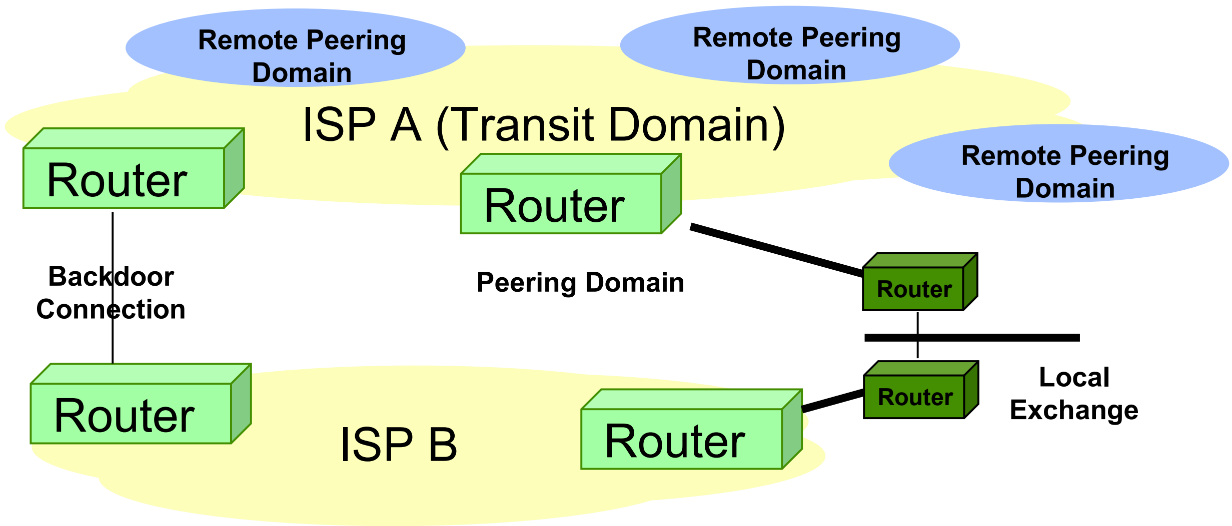
Co-location Model

- Extensions broadens the model by other services:
  - More than a pure routing and traffic exchange role.
  - Content provider supported, *e.g.*, with high volumes, selection of non-local transit providers.
  - *E.g.*, Multicast, Web, DNS, policy-based route services.

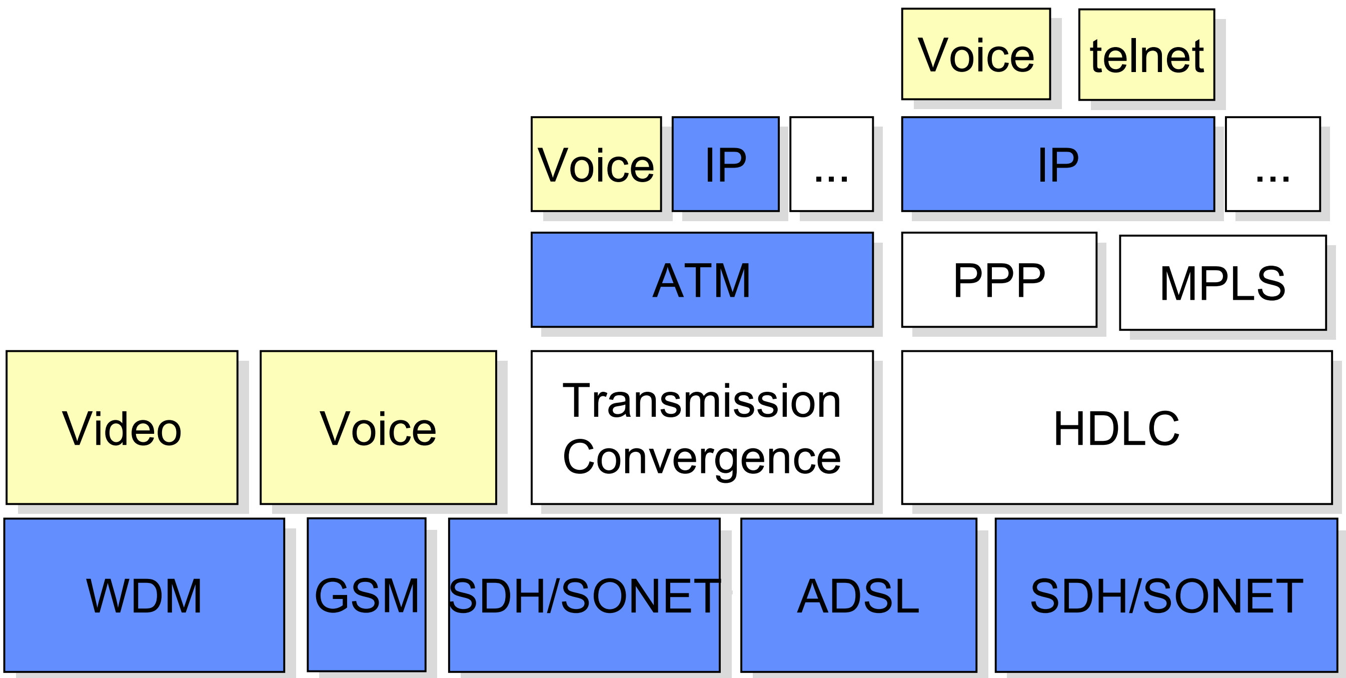


Network Access Points (NAP)

- Exchange provider between regional ISPs to exe-cute bilateral peering and transit purchase venue to execute purchase agreements with transit ISPs.
- Operational complexity (business agreements).



Protocol Diversity – Examples



ATM: Asynchronous Transfer Mode
GSM: Global System for Mobile Communication
HDLC: High Data Link Control
IP: Internet Protocol
PPP: Point-to-Point Protocol
WDM: Wavelength Division Multiplexing

IP-based Network: Basic Definitions

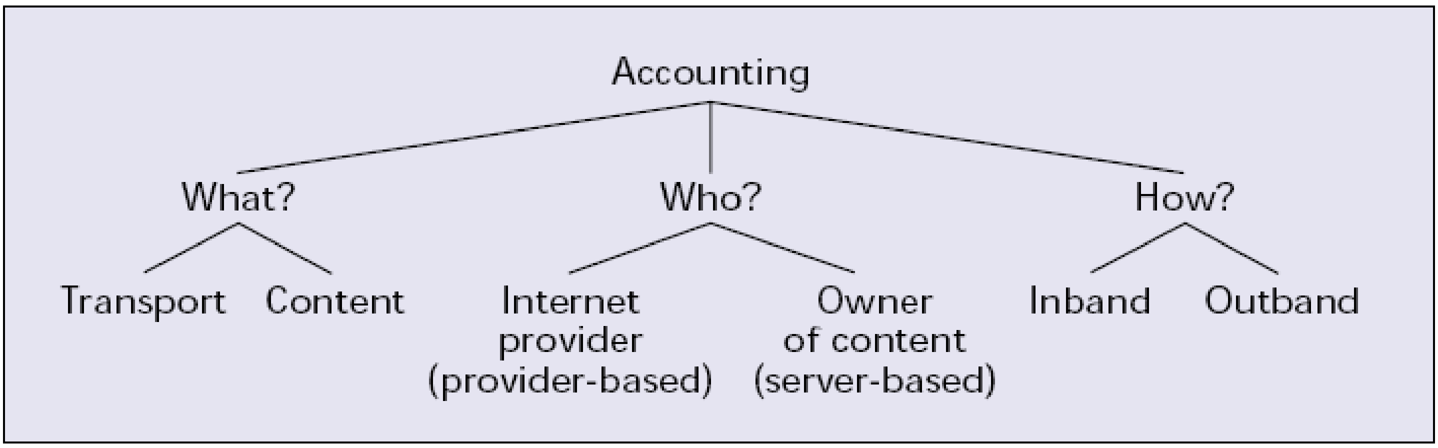
- Metering: Determining the particular utilization of resources within an end-system and the network (monitoring).
- Accounting: Acquiring and summarizing of information (accounting records) in relation to a customer's service utilization, expressed in metered resource consumption, *e.g.*, for the end-system, 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.

Terminology Comparison

IP-based Networks	3G Mobile Networks
Metering	Collecting charging information
Accounting	Charging
Accounting records	Charging Data Record
Charging options	Billing arrangements, Payment methods
Prepaid/postpaid charging	Pre-paid/post-paid billing
Charging mechanism	Charging mechanism
Billing and parts of charging	Rating (Parts of)
Inter-/Multi-Domain Charging/Billing	Accounting

Accounting Technologies and Models

Accounting Options



[A. Pras et al. 2001]

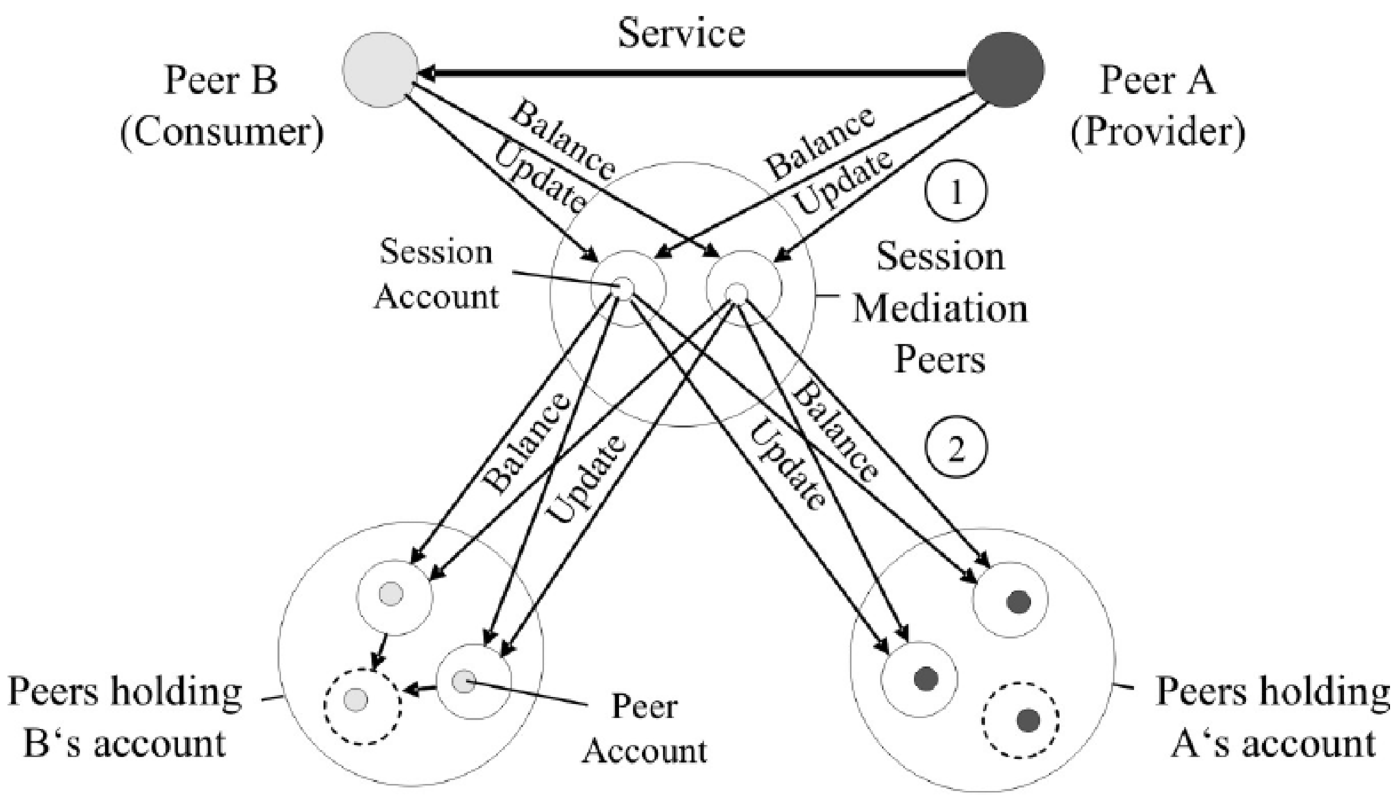
Accounting Types

- To provide functionality, which enables a book keeping of contribution or consumption of resources by service providers and service users.

- Types:
  - Local accounting: peers keep accounting data locally
    - Efficiency, but trustworthiness?
    - Token-based accounting: peers collect tokens (issued by "banks")
  - Remote accounting: other peers keep accounting data in different locations
    - Transfer of accounting data, third party principle, better credibility
    - Central accounting: central and trusted server, typically operator-based
  - Hybrid accounting: combination of the two with a "good" balance between number of peers involved and accounting data transfers between them
  - Decentralized accounting: All accounting data are fully distributed across all peers

Peers are considered as being either providers or users.

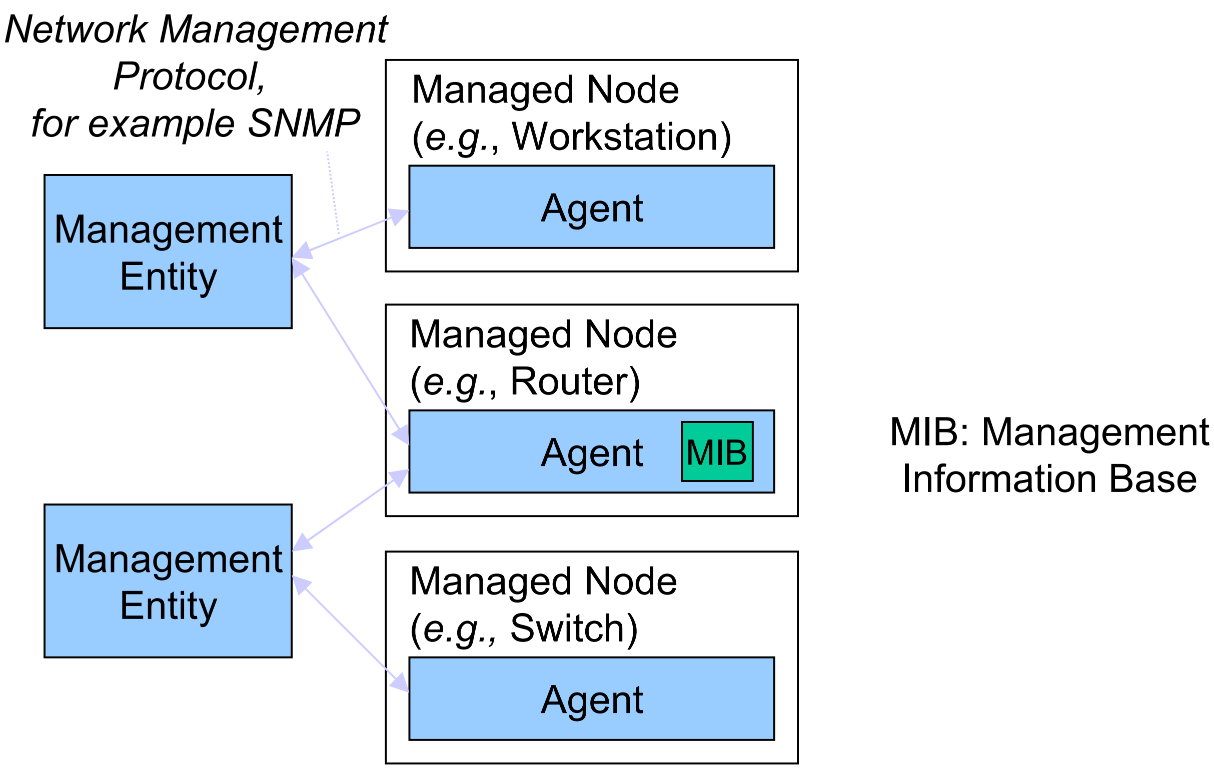
Example: Decentralized Redundant Accounting



Network Management Areas

- Fault Management
  - Recording, detection, and reaction on errors
- Configuration Management
  - Detection and configuration of existing, accessible devices
- Accounting Management
  - Specification, recording, and control of resources and the access to them
- Performance Management
  - Determination, measurements, reporting, analysis, and control of performance, *e.g.*, throughput, load, delay, or error rates achieved
- Security Management
  - Access control to resources based on pre-determined policies
  - Key management and distribution
- These areas are termed FCAPS.

Network Management Components



AAA and Security (1)

- Authentication:
  - Process of identifying *who* a user is. Typically, users prove to the system who they are by valid user name/valid password.
  -
- Authorization:
  - Process of identifying *what* a user can do. For example, after login, an authorized user may try to issue commands which are permitted. Some systems, merge authorization and authentication into a single process.
- Accounting:
  - Process of measuring resources a user has consumed. Accounting measures the amount of system time a user has used, or the amount of data a user has sent and received.

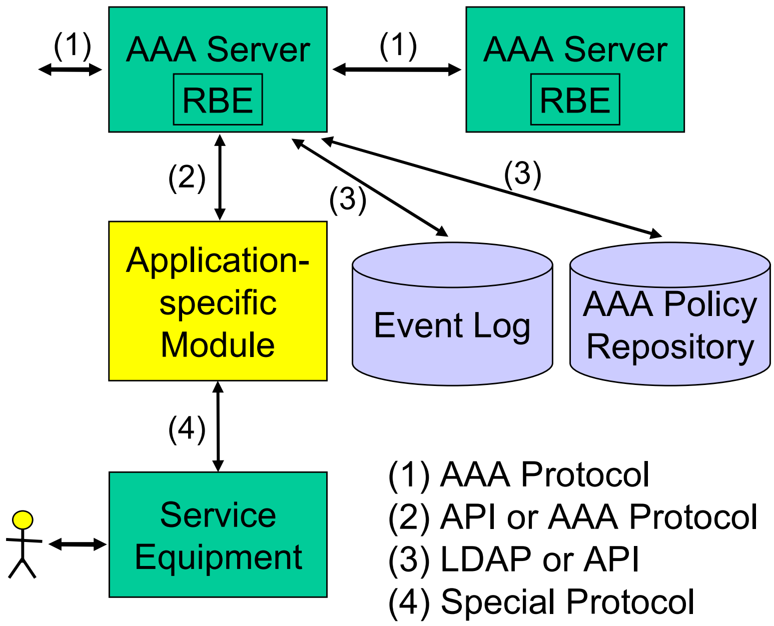
→ Authentication, Authorization, and Accounting: AAA

AAA and Security (2)

- AAA is important for effective network management and security:
  - Access of network via Network Access Server (NAS), Communication, Remote Access, or Terminal Servers
  - Control who is allowed to connect to the network
  - Control what users are allowed to do

  - Provisioning at the point of network entry, *e.g.*, dial-in users
  - Accounting of utilized resources:
    - At access (NAS)
    - Within network
    - Along communication paths

AAA Architecture



(1) AAA Protocol
(2) API or AAA Protocol
(3) LDAP or API
(4) Special Protocol

AAA Authentication, Authorization, Accounting
LDAP Light-weight Directory Access Protocol
RBE Rule-based Engine

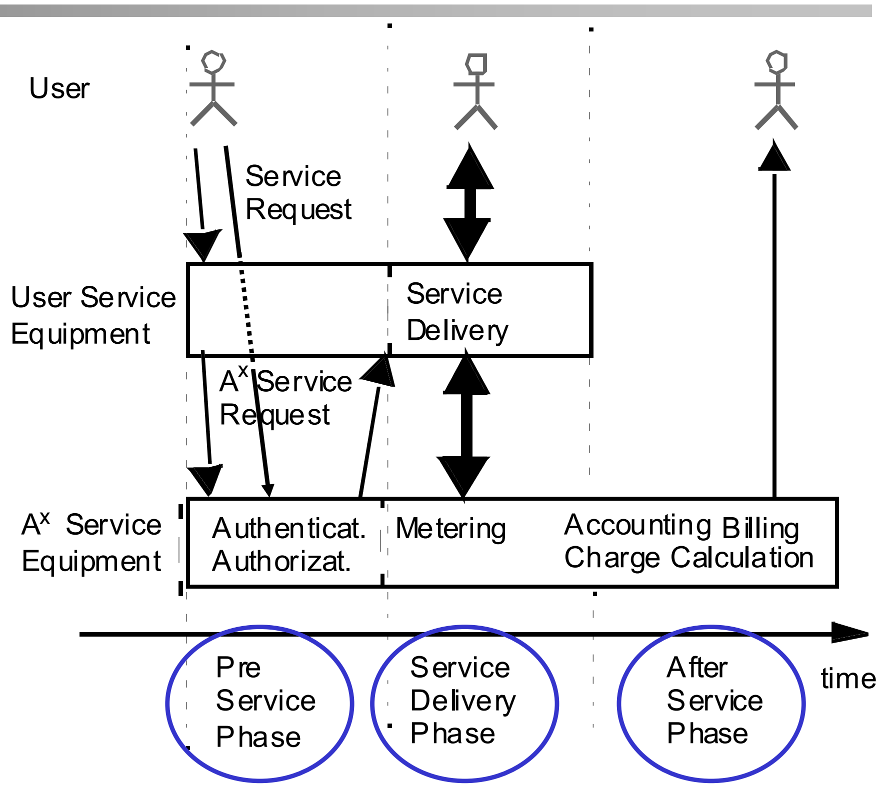
[RFC 2903]

A^x Model: Service Interactions

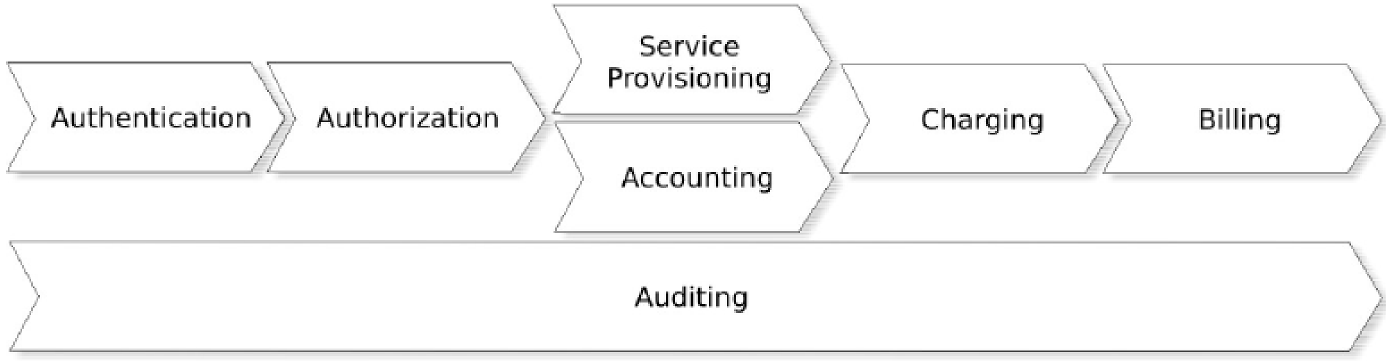
- Objective:
  - Support of multiple user services with configuration requirements
  - Generic A^x services

⇒ Logical separation

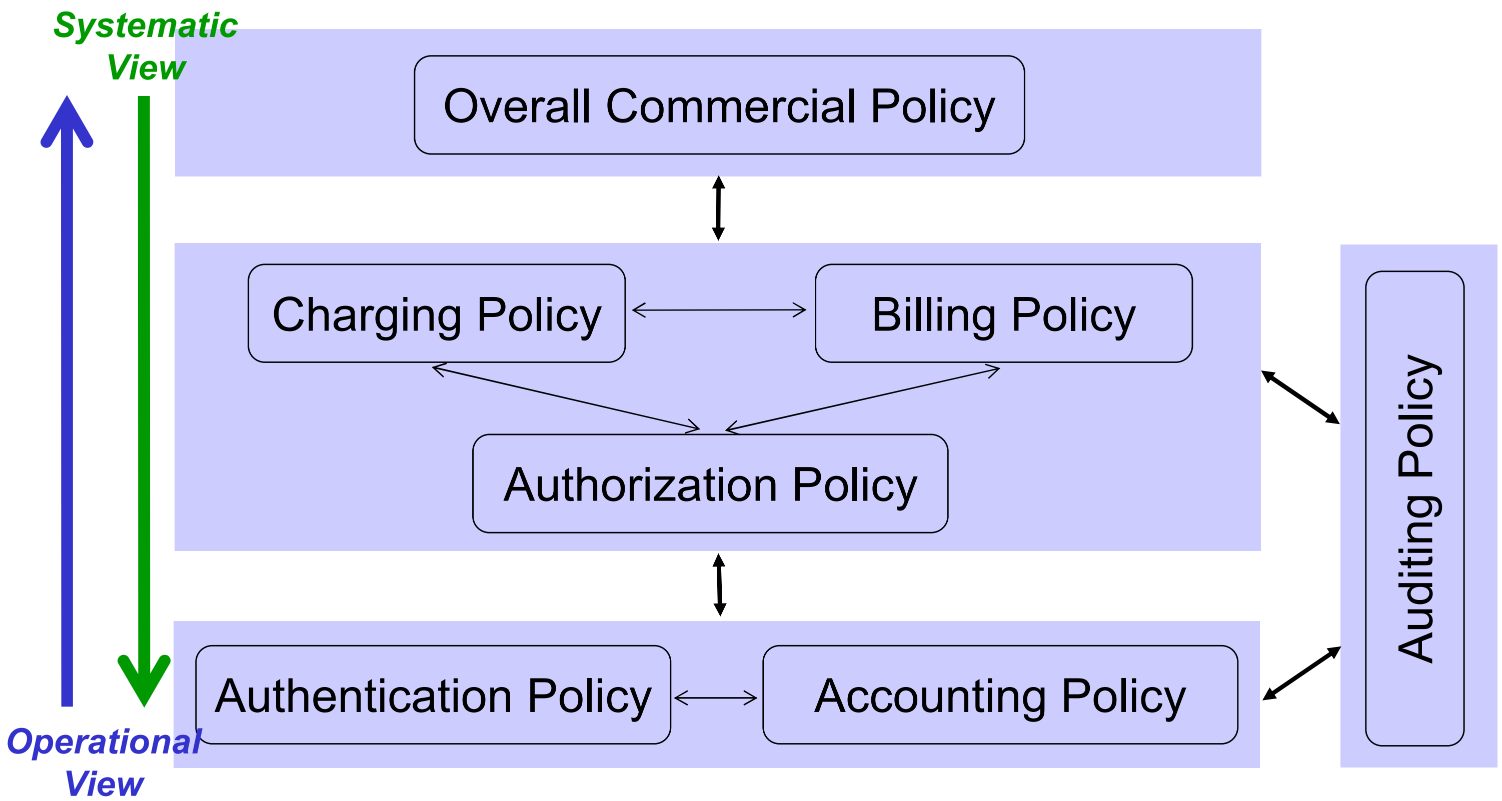
- Sequence of action:
  - Phases



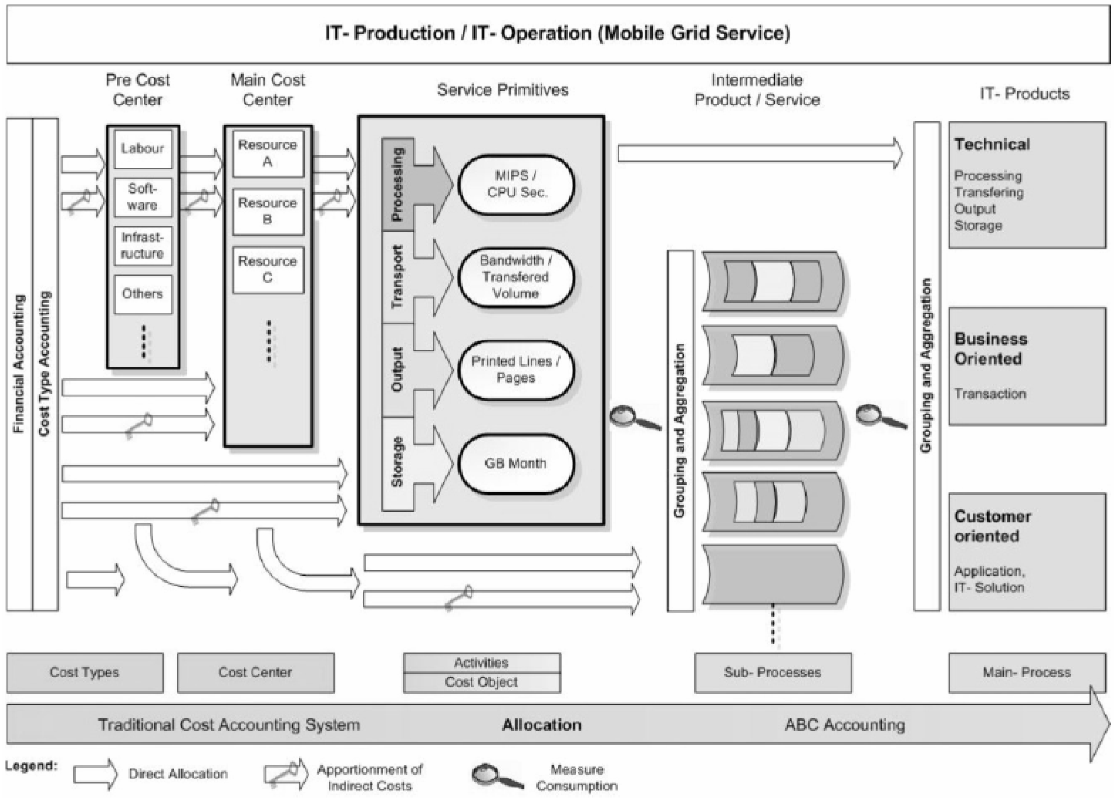
Functional Steps – Upon Service Request



Policy Model of the A^x Architecture



Example: Grid Accounting Model



RADIUS (1)

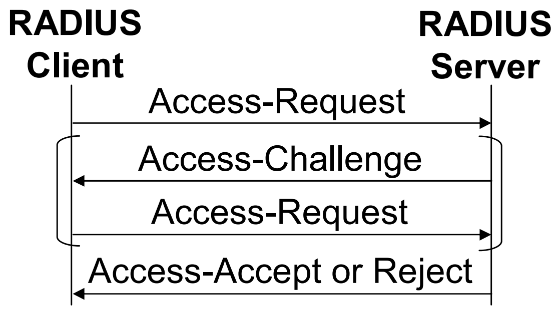
- RADIUS: Remote Authentication Dial In User Service
- Supports:
  - Authentication, authorization, and accounting mechanisms
- Client-server model, server can act as a client (proxy)
- Connectionless protocol based on UDP
- Uses attribute-value pairs:
  - Providing the ability to create vendor-specific extensions
- Applies the hop-to-hop security model
- Supports PAP and CHAP authentication via PPP
- Wide-spread deployment

PAP: Password Authentication Protocol
CHAP: Challenge Handshake Authentication Protocol
PPP: Point-to-point Protocol

[RFC 2865]

RADIUS (2)

- Messages for Access control (AA):
  - Access-Request
  - Access-Accept
  - Access-Reject
  - Access-Challenge



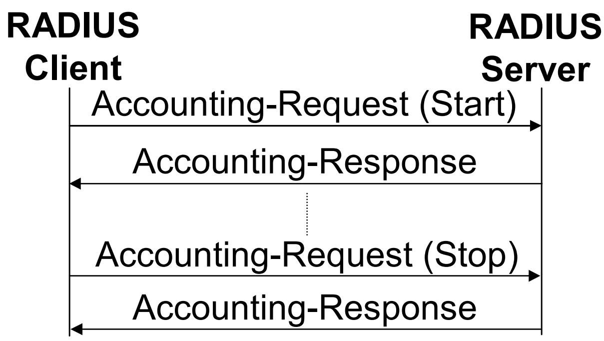
- Attribute Value Pairs
  - Value Types: Integer, Text String, IP Address, Date, Binary
  - Message size: Header size (12 bytes) + NrOfAttributes(0 ..N) * Attribute (3..255 bytes) with max 256 different attributes

Attribute Number	**Attribute Length**	**Attribute Value**

[RFC 2865]

RADIUS Accounting

- Messages for accounting:
  - Accounting-Request
    - Start
    - Stop
    - Interim-Update
  - Accounting-Response



- Accounting-specific attributes:
  - Acct-Session-Time
  - Acct-Input-Octets, Acct-Output-Octets
  - Acct-Input-Packets, Acct-Output-Packets
  - Acct-Session-ID
  - Acct-Terminate-Cause

[RFC 2866]

Security of RADIUS

- Client and server hold a shared secret
- Hop-to-hop security model
- Packet authentication based on MD5
- User password hiding based on the shared secret and the MD5 hash algorithm

- Vulnerabilities:
  - Attacks to get the shared secret
  - Weak request authentication
  - User password encryption

- It is recommended to use RADIUS over IPSec

Diameter (1)

- Diameter is another AAA protocol providing minimum requirements as defined in RFC 2989
- Diameter designed to overcome the deficiencies of RADIUS:
  - Different access technologies
  - Distributed security model
  - Multi-domain roaming scenarios
  - Server-initiated messages
  - Better error handling and reporting
  - Capability negotiation
  - Peer discovery and configuration
- Consists of session-oriented base protocol and different extensions (*e.g.*, for accounting)
- Reliable transport provided by use of
  - TCP
  - SCTP

[RFC 3588]

Diameter (2)

- Attribute-value pairs (AVPs) for data exchange
  - Extended data formats for AVP data types
  - Standardized set of AVPs is defined, but it is flexible for further extensions.
  - AVP format:

AVP Code	AVP Flags	AVP Length	Vendor-ID (optional)	Data

- Security support:
  - Hop-by-hop and end-to-end security
  - Support of IPSec and TLS
  - Auditability, data-object security mechanisms
- Messages for accounting:
  - Accounting-Request
  - Accounting-Answer
- Accounting Record types:
  - Event record
  - Start record, interim record, stop record

[RFC 3588]

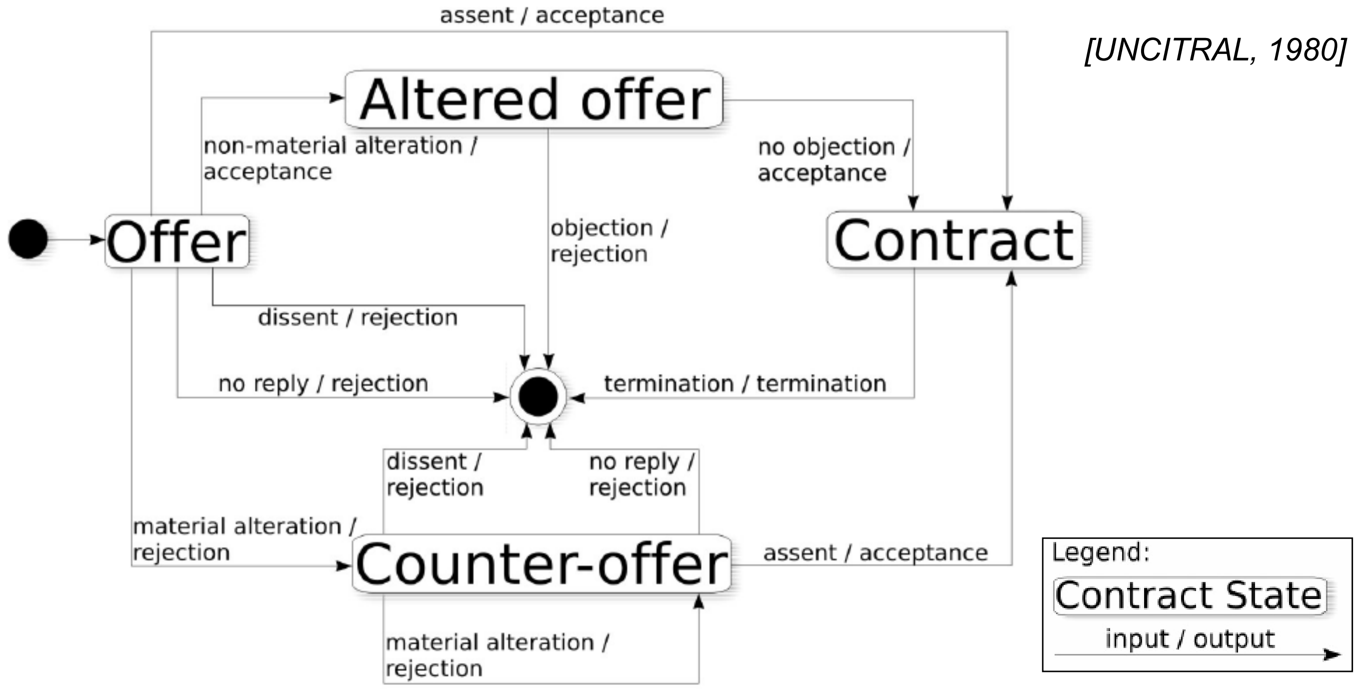
Legal Base for Service Offers (1)

- Service Level Agreements (SLA)
  - Contract between service provider and service user
  - Semi-formalized
- SLAs contain
  - Information related to service delivery itself
    - Identities
    - Service functionality
    - Service parameters
    - Service duration
  - Information related to the accounting, charging, and payment of that service
    - What service-specific information to be collected
    - Tariff/price
    - Rule in tariff/price application times
    - Method of payment
    - Reaction rules in case of contract violations

Legal Base for Service Offers (2)

- Contract formation process for contracts governed by United Nations law for the international trade of goods.

[UNCITRAL, 1980]



Charging Approaches

Basics

- Prices and tariffs fed into the charging needs to follow either
  - Marketing models
  - Service quality and respective parameters
    - Objective parameters in terms of Quality-of-Service (QoS)
    - Subjective parameters in terms of Quality-of-Experience (QoX/QoE)

- Measurable approaches are more viable in the long-run!

- Thus, in which way can charging be made measurable?
  - Utilities (economic)
  - Incentives (economic)
  - Detailed accounting parameters applied to pricing schemes (technically)
  - Feasible, efficient, and practical mappings between the economic and technical domains

Utilities

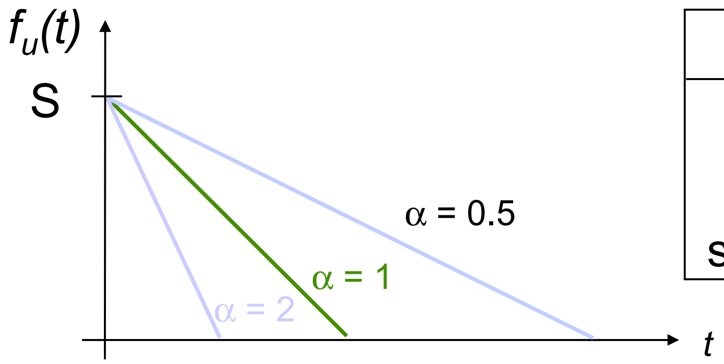
- Utility functions are required to find an optimal resource allocation, while maximizing the utilization of this resource.
  - Network or service users are modeled by their required degree of satisfaction or utility:
    - User's value of certain QoS over price.
    - Means of distinguishing diverse performance.
  - f_u: QoS $\rightarrow$ 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

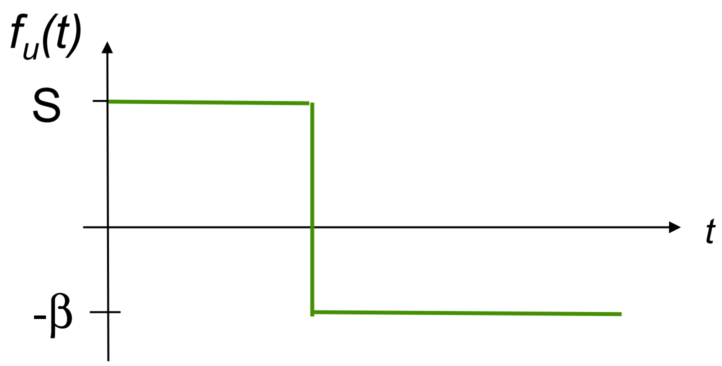
Utility	Time	Data rate
very well	1 s	8 Mbit/s
good	10 s	800 kbit/s
satisfactory	60 s	133 kbit/s

α "proportional" to price.

Utility Functions – Examples (2)

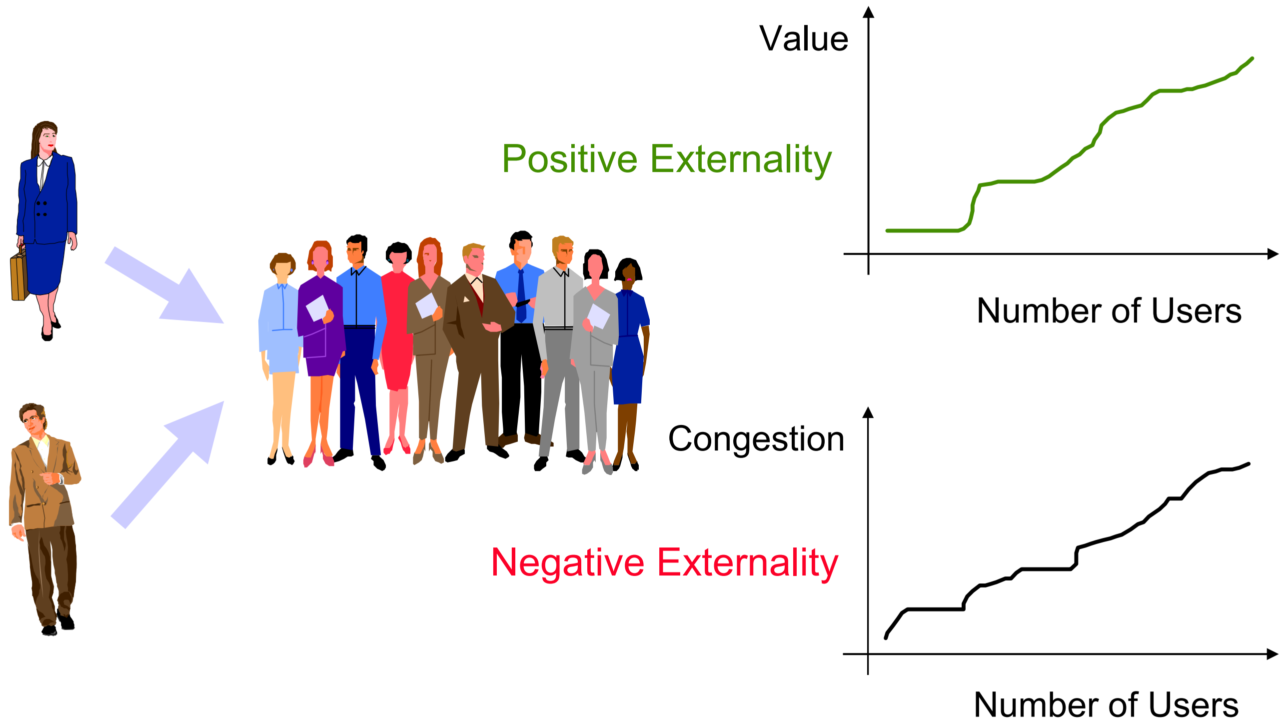
Based on [Kesh97]

- 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 ...

Incentives

- Incentive mechanisms divided into two groups
  - **Trust-based incentive mechanisms**
    - Peers encouraged to act to gain as much trust as possible. A positive behavior increases trust value, negative behavior decrease trust value.
  - **Trade-based incentive mechanisms**
    - Resources are exchanged and peers are encouraged to provide in order to consume. The advantage: misconduct results immediately in a penalty.

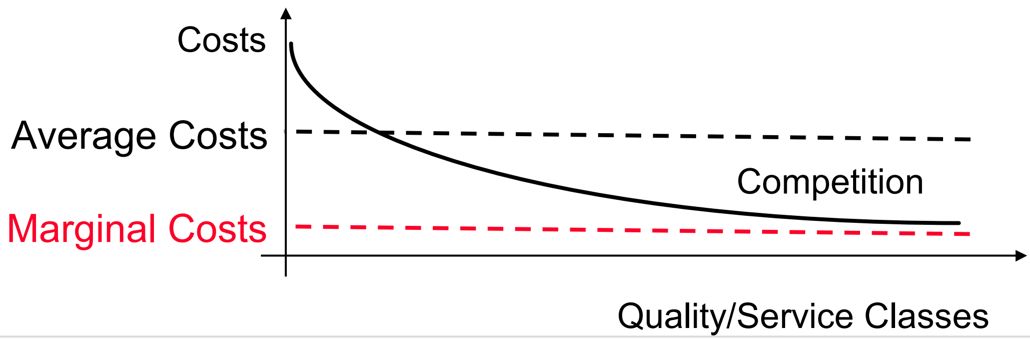
[P. Obreiter and J. Nimis. A Taxonomy of Incentive Patterns - The Design Space of Incentives for Cooperation, 2003]

Mechanism	*Reci-procity*	*Indirect Reciprocity*	*One Hop*	*Collusion Resistance*	*Exhaustive Hop Search*
BarterCast [65]	yes	yes	yes	yes	no
One-hop reputa-tion [89]	yes	yes	yes	yes	no
GtG [68]	no	no	yes	no	n/a
STFT [95]	yes	no	no	yes	n/a
MaxFlow-based algorithm [39]	yes	yes	no	yes	no
PSH1 [17]	yes	yes	no	yes	no
PSH_r [17, 11]	yes	yes	yes	yes	no
CompactPSH [11]	yes	yes	yes	yes	yes

[T. Bocek, 2009]

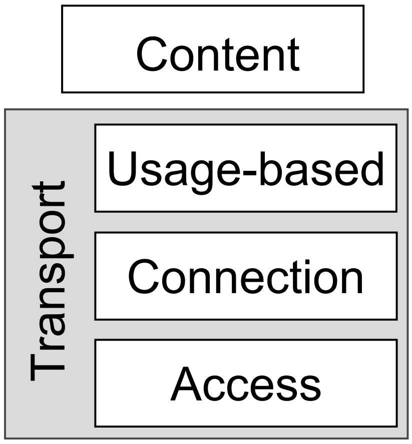
Pricing based on Parameters

- Quality supports service differentiation!
  - QoS parameters measurable: throughput, delay, jitter, loss, out-of-order
- Quality increases service value!
  - QoE parameters measurable
- 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.

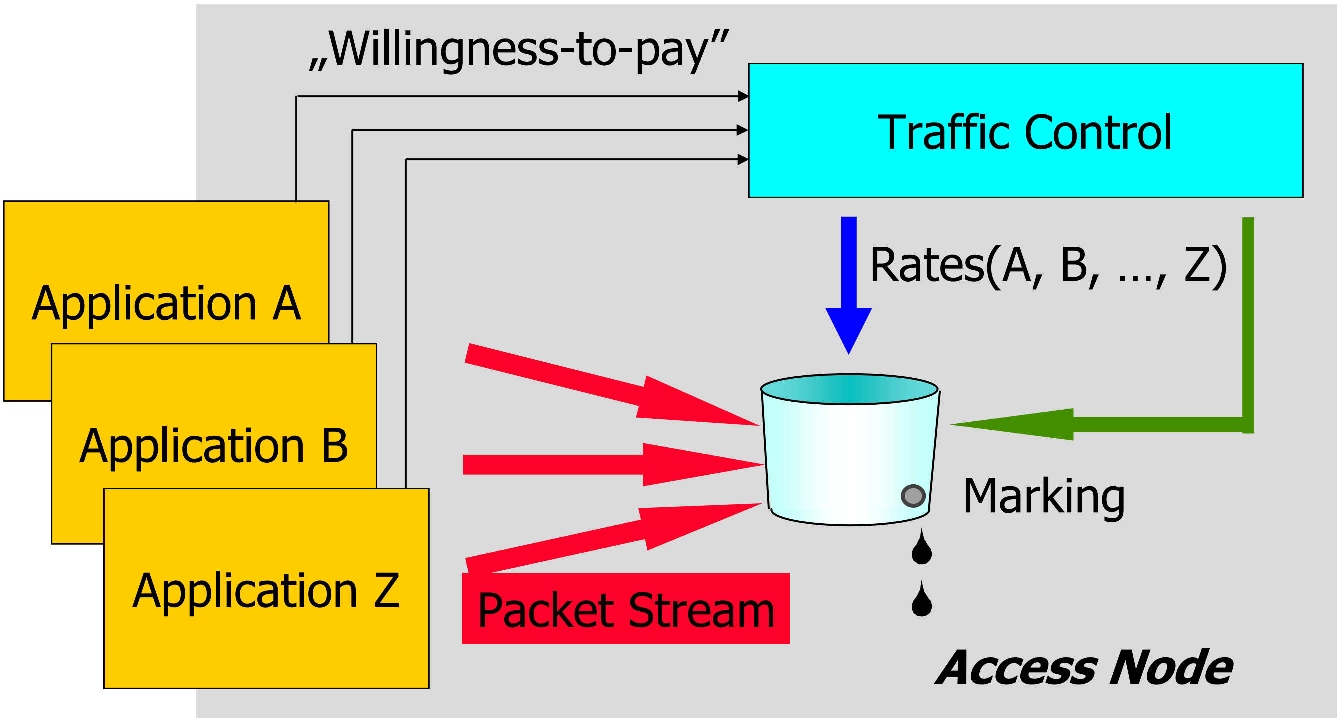


Pricing Components

- 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).

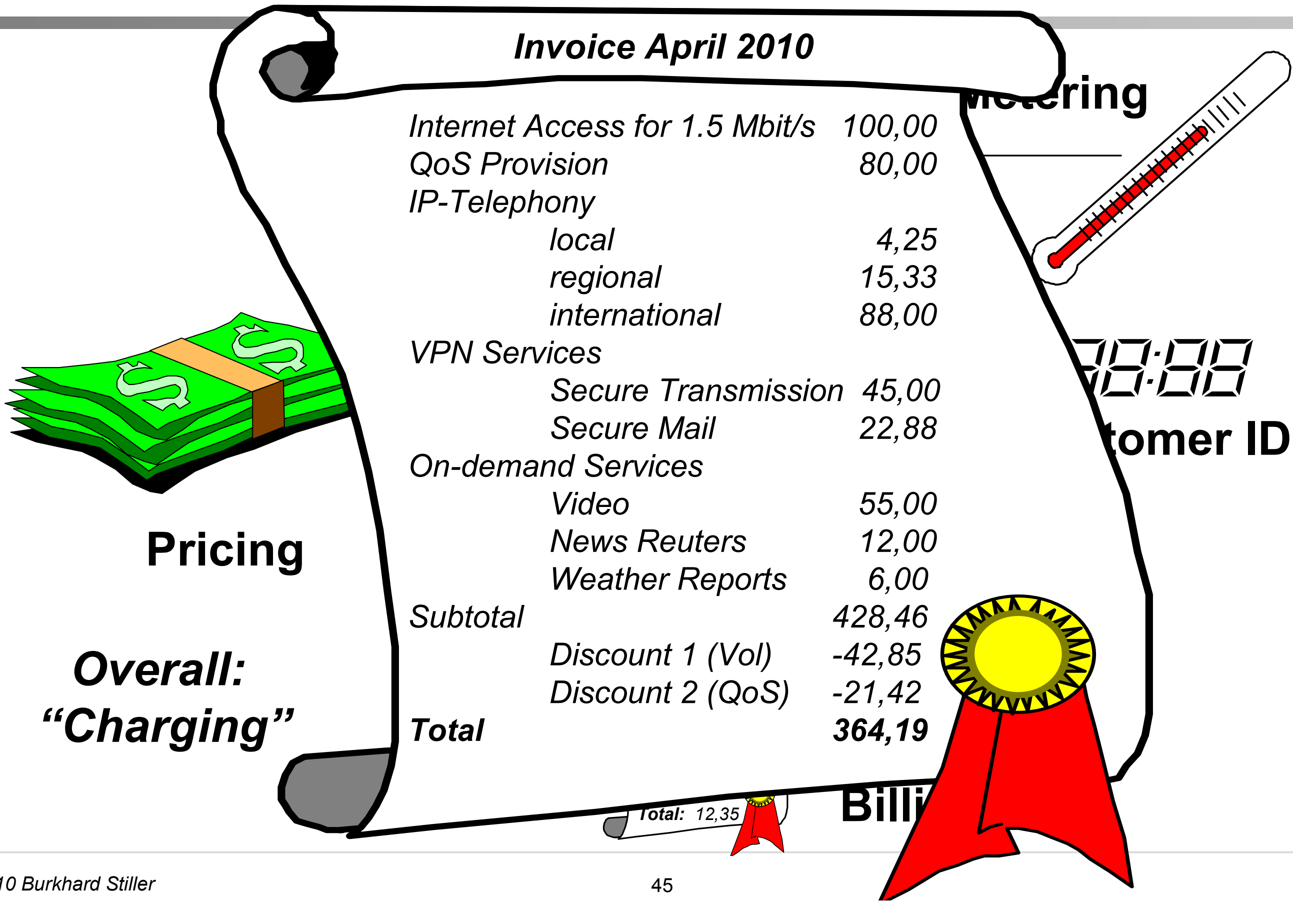


Generic Architecture of an Access Nodes

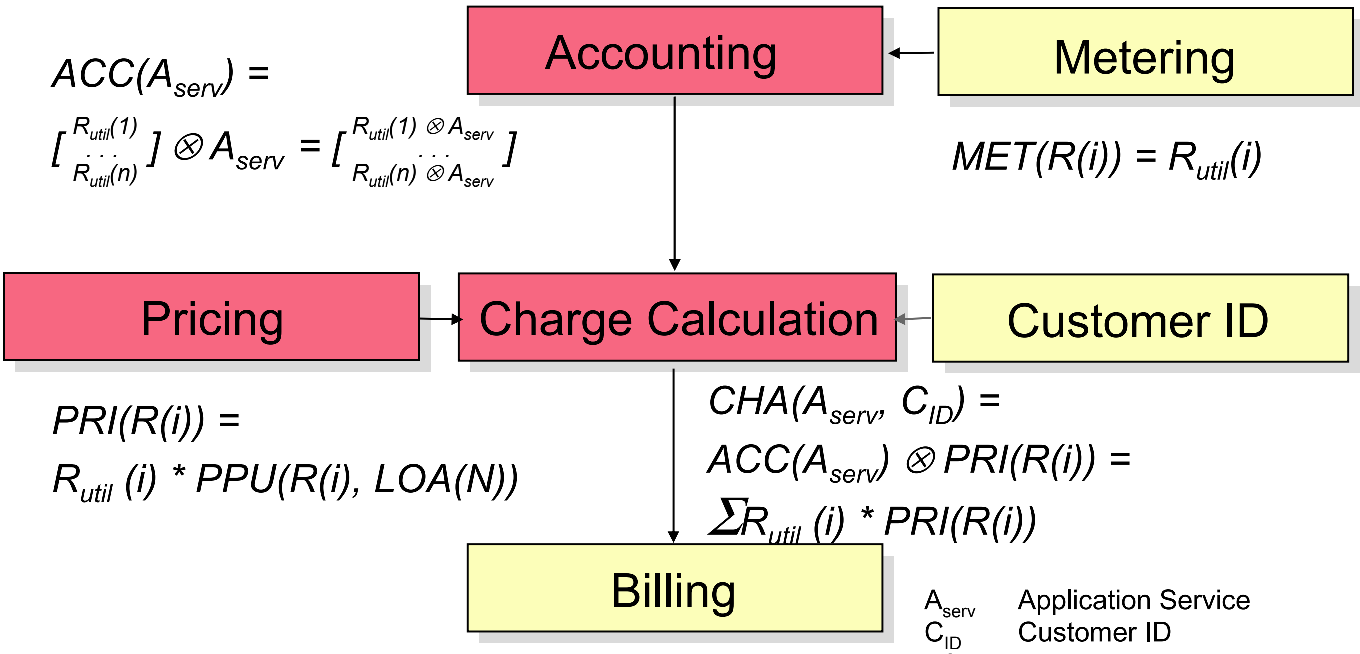


- Fairness is based on willingness-to-pay.

Architectural Components



Formal Architecture



$ACC(A_{serv}) = [R_{util}(1) \; ... \; R_{util}(n)] \otimes A_{serv} = [R_{util}(1) \otimes A_{serv} \; ... \; R_{util}(n) \otimes A_{serv}]$

$MET(R(i)) = R_{util}(i)$

$PRI(R(i)) = R_{util}(i) * PPU(R(i), LOA(N))$

$CHA(A_{serv}, C_{ID}) = ACC(A_{serv}) \otimes PRI(R(i)) = \Sigma R_{util}(i) * PRI(R(i))$

$BIL(C_{ID}) = \Sigma CHA(A_{serv}, C_{ID})$

A_{serv}	Application Service
C_{ID}	Customer ID
LOA	Load
N	Network
PPU	Price per Unit
R(i)	Resource i
R_{util} (i)	Utilization of Resource i

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

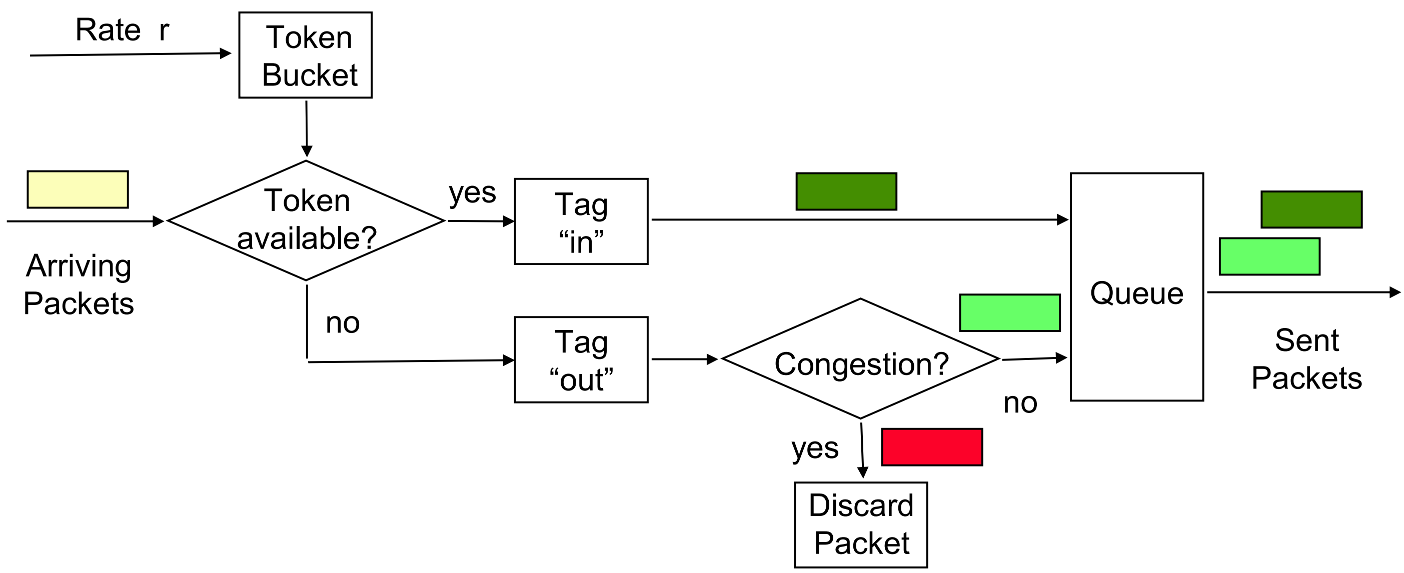
- Provisioning of ”sufficient“ bandwidth.
  - Possible due to small/decreasing cost.
  - Regional cost differences.
  - Still, decreasing cost.
- Advantage:
  - Larger bandwidth for the same amount of money.
- Drawback:
  - There is no natural limit for bandwidth usage.
  - Cost are not limited by an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

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 (DiffServ-like).
  - *E.g.*, at hosts or border routers.

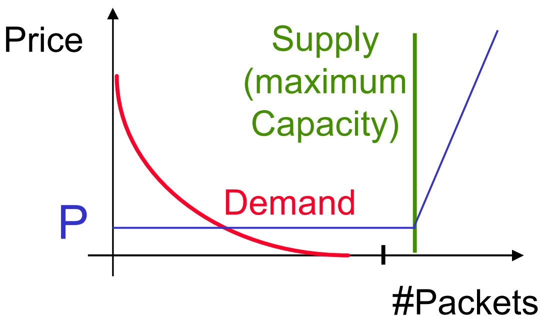
Pricing Expected Capacity (2)

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

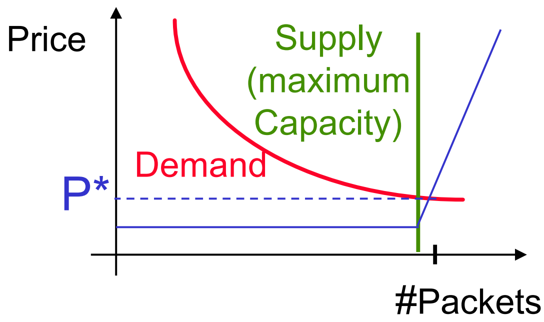


Smart Market

- 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.

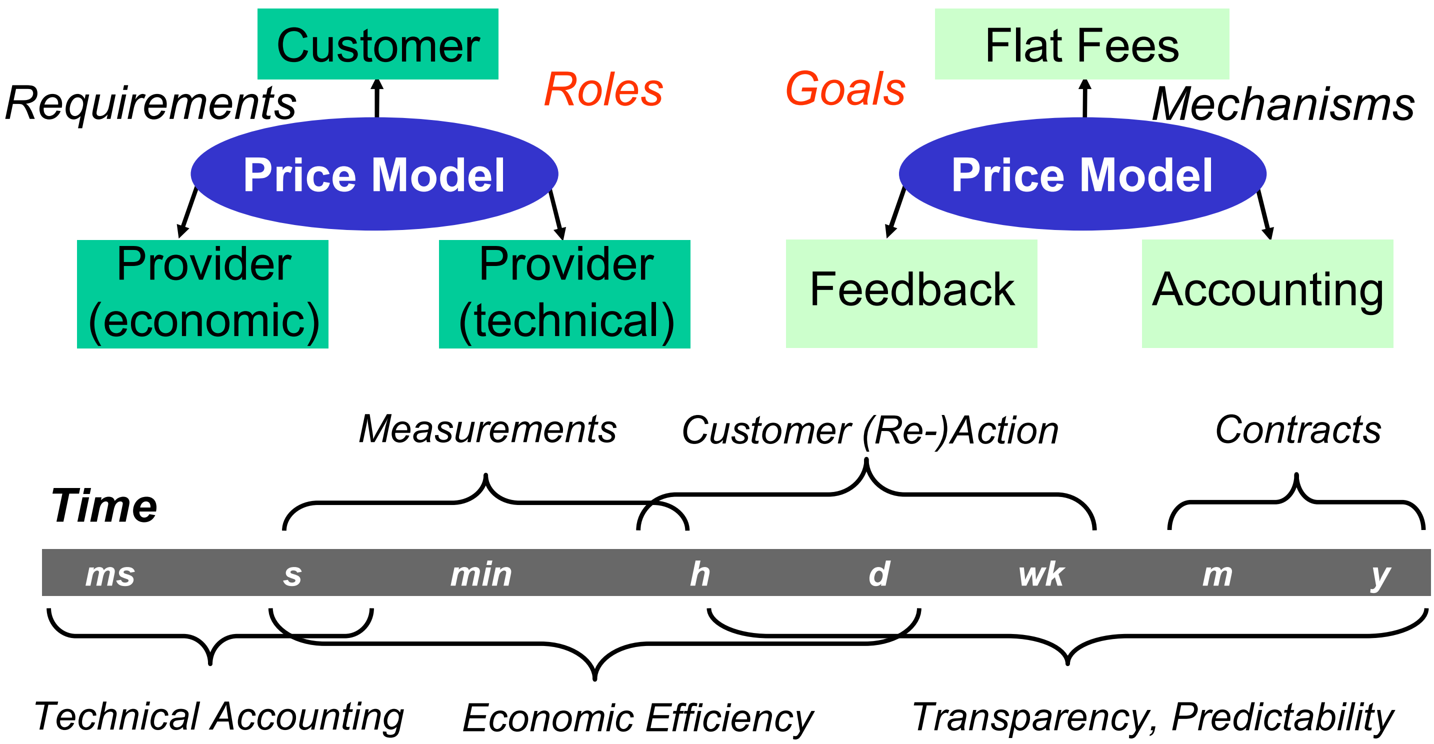


P: Base price, if
#packets ≤ max. capacity.



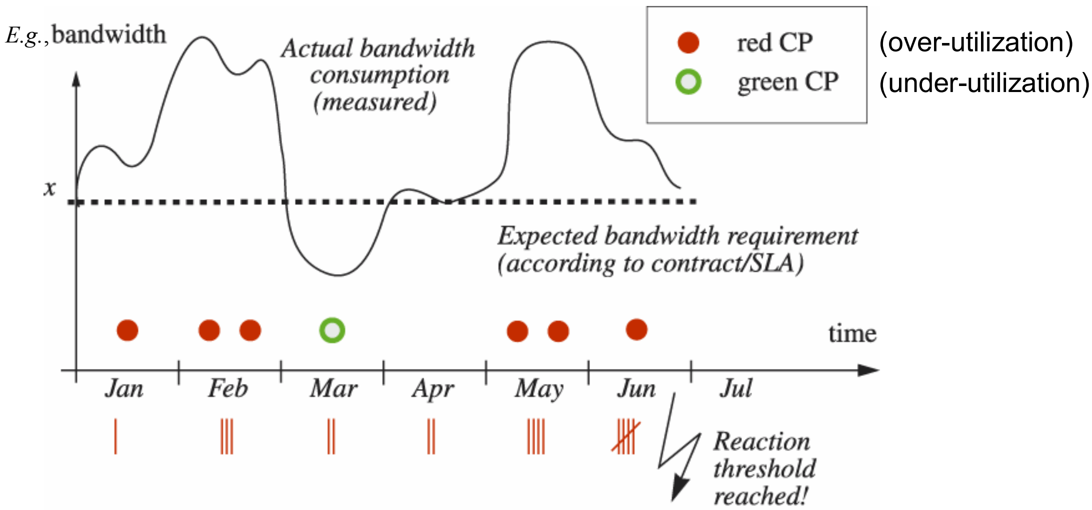
P*: Auction price, if
#packets > max. capacity.

Time-scale "Trilemma" of Internet Pricing



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.

Formal Definition of CPS

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

i.e.,

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

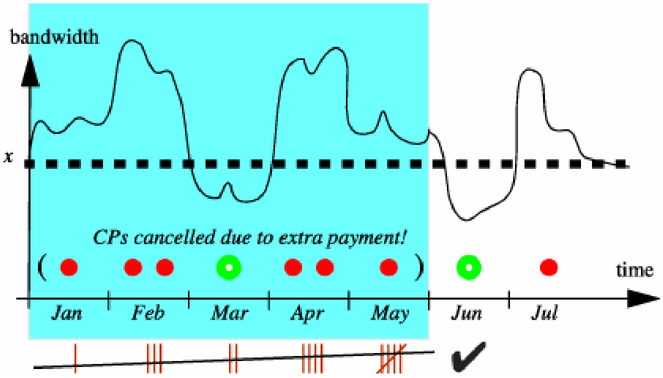
- t_i describes end of measurement period i.
- θ_{c_i} defines thresholds for CP assignments.

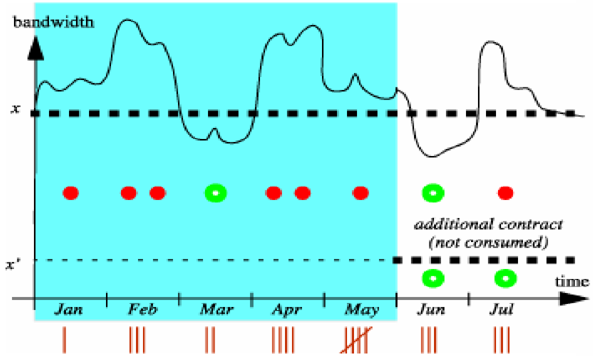
❑ CPs assigned: $0 \le \theta_{c_i} \le \Delta_i < \theta_{c_i+1}$ or $\theta_{c_i-1} < \Delta_i \le \theta_{c_i} \le 0$

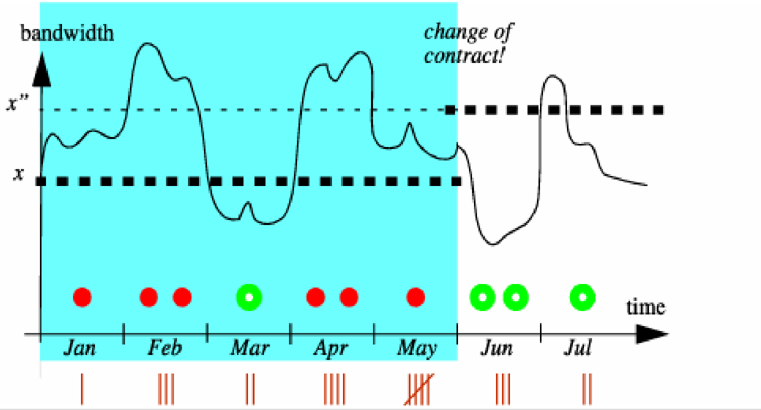
❑ Reaction threshold: Θ imbalanced contract: $|\Gamma_n| \ge \Theta$

CPS Reaction – Long Time-scale

– A policy-driven price management:
  • Extra payment.
  • Additional contract.
  • Different contracts.



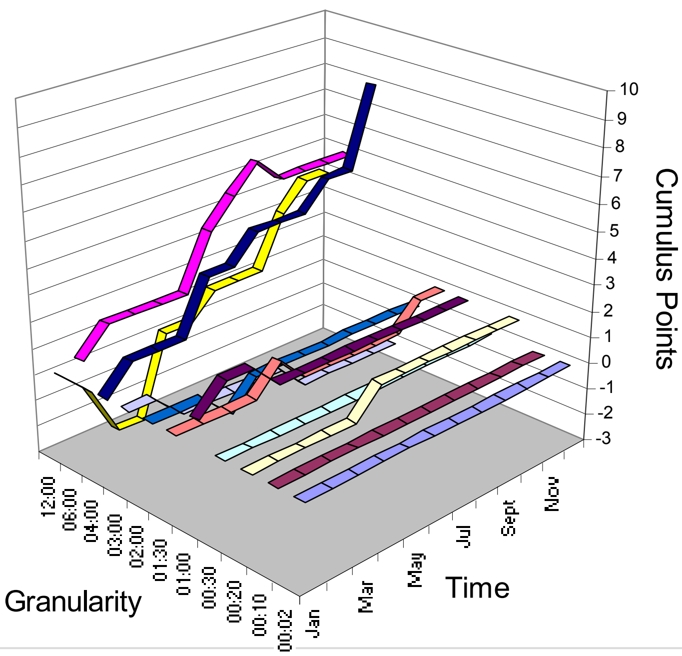




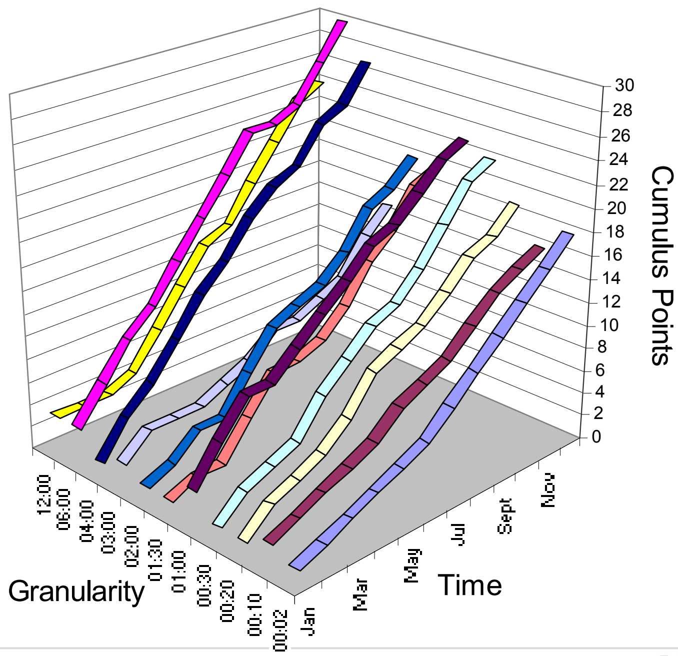
CPS Stability: Different Sampling Intervals

❑ CP assignments of real-world network traffic:

For correct traffic estimation x.



For 10% underestimation of x.



CPS Characteristics

- CPS shows key characteristics of:
  - Handling of user *and* provider requirements.
  - Addresses rare resources, *e.g.*, frequencies, airtime.
  - Roles re-visited:
    - Customer: Flat-fee like.
    - Provider (economic): Feedback signals (Cumulus Points).
    - Provider (technical): Sampled accounting possible.

- CPS solves the “Trilemma“ (feasibility problem):

> Technical feasibility of an ISP pricing scheme is *more stringent* than user preferences or economic efficiency, but it requires a viable balance.

Conclusions

Conclusions and Future Work

- Charging and accounting for IP services needs to
  - Combine efficiently economic and technical constraints
  - Avoid optimization of approaches in one dimension only
  - Work "properly" in operational settings
  - Support a variety of underlying networking technologies and systems
  - Eventually solve the "Feasibility Problem" of Internet pricing
- Existing solutions do address in almost all cases only parts of those requirements; they are service- or technology-specific.
- Future work has to address, a.o. aspects, the following ones:
  - Determine "optima" in an integrated manner (economic *and* technical)
  - Address work on user behavior and reactions onto price models and tariffs
  - Optimize the technical infrastructure needed for flexible charging approaches
    - Considering post- and pre-payment systems

Acknowledgements

- The content of this material is based on joint work and many discussions in the last 12 years with the following people:
  - Dr. David Hausheer
  - Dr. Peter Racz
  - Dr. Jan Gerke
  - Dr. Thomas Bocek
  - Dr. Peter Reichl
  - Dr. Pascal Kurtansky
  - Cristian Morariu
  - Martin Waldburger
  - Dr. Jim Roberts
  - Prof. Dr. Aiko Pras

[A full list of references is available upon request.]

Many thanks are addressed to fruitful, joint meetings!