The Cost of QoS: Network Pricing Techniques and Trends

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Network Resources and QoS

- Wide variety of network applications
  - Many require certain Quality of Service (QoS)
  - Achieved through proper resource allocation
- Network resources
  - Bandwidth, buffer space and processor time
  - **Shared** and **finite**
- Resource demands continue to increase
  - New *killer* applications and more users

The Tragedy of the Commons

- Want to prevent *The Tragedy of the Commons*
  - Shared finite resource with no *direct* feedback
  - Consumers will always desire more
- Pricing can provide
  - Network control
  - Optimal resource allocations
  - Mechanism for cost recovery

Pricing Misconceptions

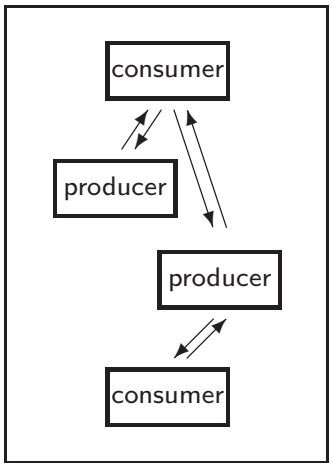
- No congestion, supply will be greater than demand
- Pricing will be based on content only; *information economy, not a resource economy*
- Economists have already solved this problem
- Current telephone pricing model is adequate

Resource Pricing

- Pricing goals
  - Competitive
  - Usage-sensitive - time and volume (not flat)
  - Incentive for users to conform (market demands)
  - Differentiated pricing (value across services)
- Service types
  - Guaranteed - QoS, price or resources? How long?
  - Best effort (elastic traffic) - No guarantees but fair treatment

Competitive Market Model

- Model - **consumers**, **producers** and **scarce resources**



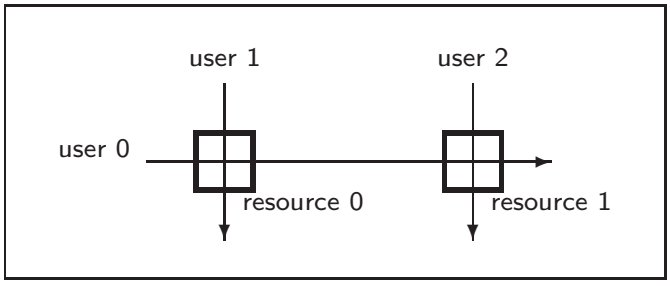
- Prices
  - Influence behavior
  - Based on supply & demand
  - Equilibrium when demand = supply
- Advantages
  - Maximize utility (QoS)
  - Optimal and fair distributions

Optimality and Fairness

- **Pareto-optimal** (economics) - No one can increase their utility without decreasing the utility of another
- **Weighted max-min** (network) - Indifferent to the number of *hops*
- **Proportionaly fair per unit charge** (network/economic) - Considers the number of *hops*
- Social welfare (economics)
  - **Equity criterion** - Equal utility
  - **Utility criterion** - max$\{\sum$ utility $\}$

Which is appropriate?

Fairness Examples



Assume each resource has supply of 1.

- Max-min fair - allocaton $\{\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\}$
- Proportionally fair per unit charge - allocation $\{\frac{1}{3}, \frac{2}{3}, \frac{2}{3}\}$

Economics and Networks

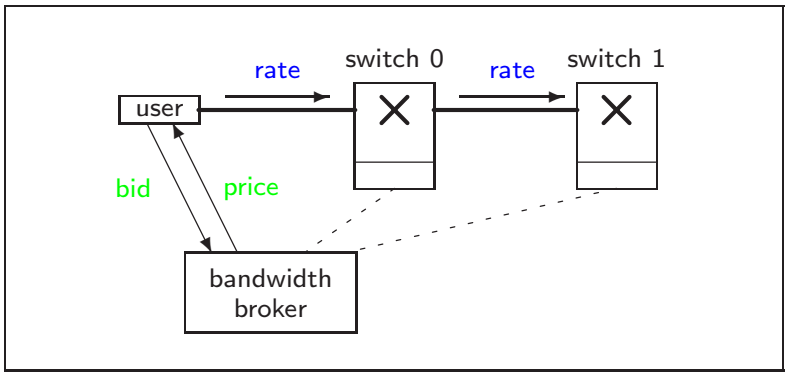
Using a market model for network resource pricing

- Users ≡ consumers
- Switches ≡ producers
- Link bandwidth ≡ resource

Implementation issues

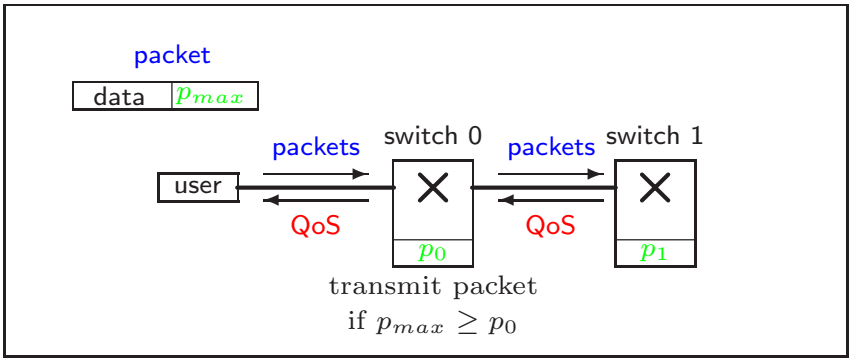
- Where and how is the price set?
- How long is the price valid (time scale)?
- How is market information distributed?
- Is the method scalable?

Auction Methods



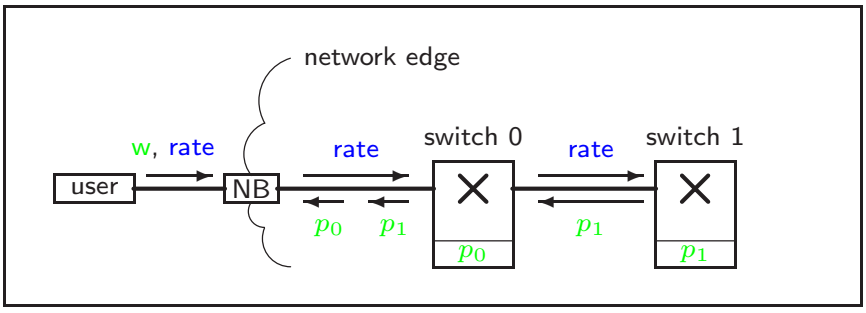
- Users bid at centralize broker for resources
- Auction must close before resources are sold
- Large time scale (bidding process)
- Appropriate for long term agreements

Smart Market



- Users place bid in data packets
- Switches forward packets based on bid and local price
- Feedback based on observed QoS

Spot Market



Model consists of - switches, users and Network Brokers

- Switch - Each link is an independent market
- User - Seeks resources
- Network Broker (NB) - Represents the user

Spot Market

- Switch
  - Prices updated based on supply and demand
  - Bandwidth is a **non-storable** resource
  - Immediate availibility (no reservation overhead)
- User
  - Charged for usage (similar to residential electricity)
- Network Broker (NB) - Represents the user
  - Located at the network edge
  - Maximizes utility (QoS)

Spot Market Performance

Constant demand

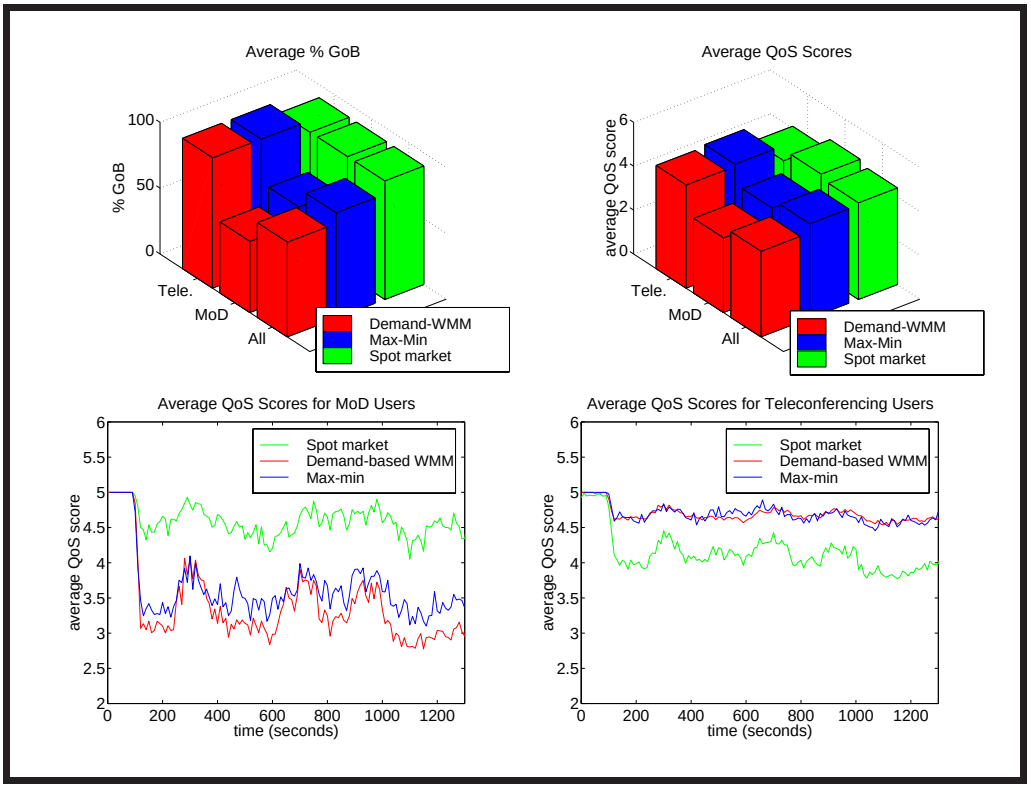
- Proofs of optimal and fair allocations

Network dynamics - simulations

- Optimal allocations over 92% of the time

Example Simulation Results

- Compare *perfect* max-min and demand WMM
- Measure QoS, desire *equitable* allocation
- 152 users - MPEG videos and random start times
- Two types of users *MoD* and *Teleconferencing*



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Spot Market Approach

Advantages	Disadvantages
• Distributed	• No guarantees
• Little a priori info required	• Profit maximization?
• Low implementation cost	
Stateless & simple calc.	
⋆ Efficient & fair allocations	
⋆ Calculation at network edge	
⋆ Allows demand changes	
⋆ Immediate availability	

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Multi-Market

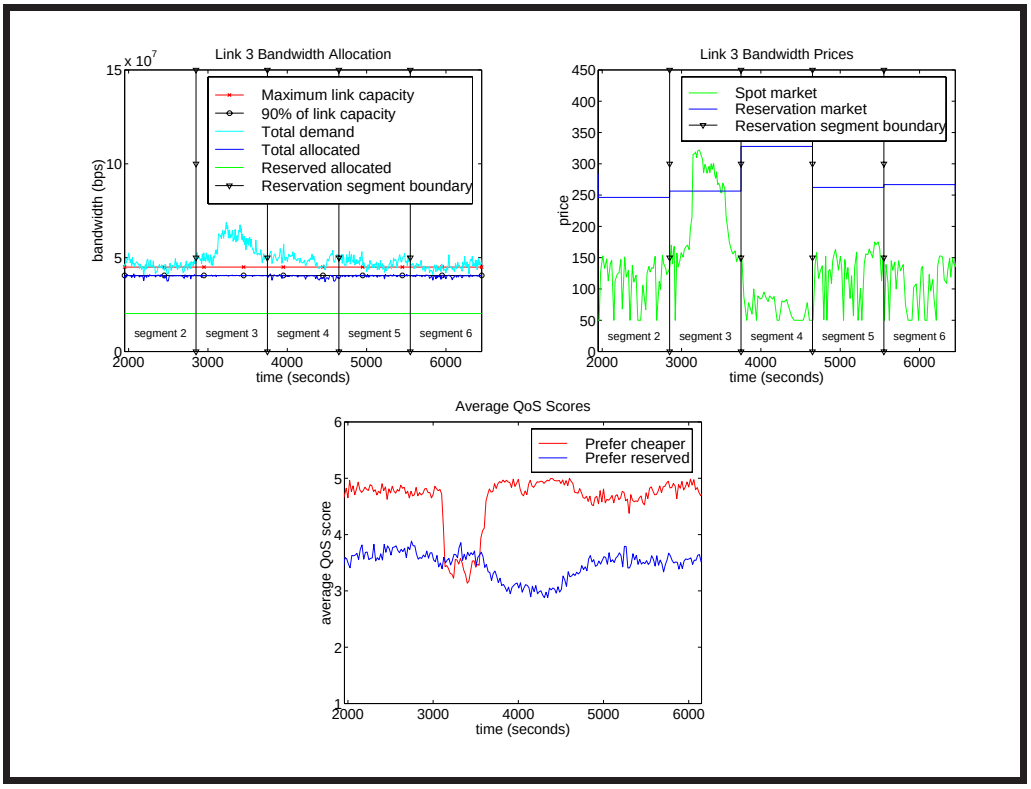
Provides **guarantees**
Model consists of: switches, users and NBs

- **Switch** - two markets per link (reservation & spot)
  - Reservation market
    - Bandwidth divided into equal segments of time
    - Portions of the segment are sold via auction
    - Any unused bandwidth is sold as spot
- **User/NB**
  - Preferences described with an indifference curve
  - NB maximizes the utility

Multi-Market Simulation

Demonstrate advantages of multi-market economy

- Seven link *parking-lot* network configuration
- Segment length was 15 minutes
- Each user transmitted a MPEG video and were
  - Long-term (120 total)
    - 1/2 prefer reserved, remaining prefer cheaper
  - Short-term (40 total)
    - Prefer cheaper, cause sudden demand shift



Multi-Market Approach

Advantages	Disadvantages
⋆ Immediate availability and guarantees ⋆ Users can purchase various types ⋆ Users can modify choices as prices change	• Guarantee duration

Current Bandwidth Pricing

Data carriers (UUNET, MCIWorldCom and AT&T)

- Pricing
  - Tier pricing based on *average* monthly usage

Rate	Cost
0 - 100Kbps	x
101 - 200Kbps	$2x$
$\vdots$	$\vdots$

  - Price protected, 384Kbps tier price (*flat rate*)
- Most offer a Service Level Agreement (SLA)

Service Level Agreement

Contract between carrier and client specifying:

- Type of service
- Network reliability
- QoS (latency and loss)
  - Application - average QoS for an application
  - Network - average QoS (currently offered)
- Monitoring method
- Compensation

Bandwidth as a Commodity

- What is required
  - Carriers interconnected
  - QoS standards developed and measured
  - Master agreements (no one-off contracts)
- Bandwidth traded based on price, term and amount
- Want transactions to *close* quickly (within seconds)

Current Bandwidth Markets

- Current markets include
  `www.band-x.com`, `www.rateexchange.com`, and `www.bandwidth.com`
- Companies
  - Interconnected via *pooling points*
  - Post capacity needed or offered
- Markets match potential buyers and sellers
  - Negotiations may take days to weeks
  - During the negotiation the *value* may change (opportunity cost).

Future Research

- Pricing for security and fault tolerance
  - Prevent Denial of Service (DoS)
  - ARQoS and MARX projects
- Pricing for IP Differentiated Services (DiffServ)
  - Differentiated pricing based on QoS classes
  - Association of SLA and pricing
  - Pricing a single connection in an aggregate flow

Additional Information

`http://www2.ncsu.edu/eos/service/ece/project/rtcomm/ewfulp/WWW/index.html`

- Pricing links
- Market descriptions
- SLA descriptions and link