Resource Allocation and Pricing for QoS Management in Computer Networks

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Bastille Day

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Resource Allocation & QoS

- Quality of Service (QoS) achieved with the proper allocation of network resources
  - Processor time, buffer space, link bandwidth

- Allocation view point
  - Single-user allocation - Efficient allocation to provide QoS for one user
  - Multi-user allocation - Efficient and fair allocation to all users to provide QoS
Thesis Contributions

Single User Allocation

- Dynamic Search Algorithm (DSA+)
  Refereed publications - RTSS’96, JCIS’97, ICNP’97

Multi-User Allocation

- Competitive Market Fairness Proofs
- Spot Market Approach
  Patents pending - US and Japan No. 08/971,127
- Multi-Market Approach
  Conference submission - EC’99

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Multi-User Resource Allocation

Allocation Goals

• *Efficient* - High utilization
  • *Fairness* - Network and economic oriented

Allocation Classifications

• Centralized or distributed
• Static or dynamic
• Stateless or state-maintaining
• Microeconomic-based
Microeconomics — The study of the allocation of scarce resources among competing ends. *Nicholson*

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

- **Advantages**
  - Maximize utility
  - Optimal distributions
  - Many models and methods
## Previous Microeconomic-Based Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>Constrained max.</td>
<td>Jiang [51]</td>
</tr>
<tr>
<td>ATM VC pricing</td>
<td>Ferguson [32]</td>
</tr>
<tr>
<td>Eff. bandwidth</td>
<td>Kelly [55]</td>
</tr>
<tr>
<td>Smart-market</td>
<td>MacKie-Mason [70]</td>
</tr>
<tr>
<td></td>
<td>centralized</td>
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<td></td>
<td>CBR only</td>
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<td></td>
<td>stat. models</td>
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<td>implement.</td>
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</table>

Want a microeconomic-method that,

- Distributed
- Little a priori info
- Allows demand changes
- Low implementation cost
Competitive Market Model

Priced-based model proposed by Léon Walras in 1874

- Price influences behavior
- At *equilibrium* the allocation is optimal

Economy consists of multiple competitive markets

- Markets are separate and independent
- Consumers can participate in multiple markets
- Used in the *spot* and *multi-market* approach

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Optimality and Fairness

In an economy consisting of multiple competitive markets, \( \{a\} \) (allocation array) is _______,

- **Pareto-optimal** if no one can increase their utility without decreasing the utility of another.

- **Weighted Max-Min Fair** if, for any other feasible allocation \( \{\hat{a}\} \), \( \exists j: \hat{a}^j > a^j \implies \exists k: \frac{\hat{a}^k}{w^k} < \frac{a^k}{w^k} \leq \frac{a^j}{w^j} \)

- **Equitable** if, for any other feasible allocation \( \{\hat{a}\} \), \( \exists j: u^j(\hat{a}^j) > u^j(a^j) \implies \exists k: u^k(\hat{a}^k) < u^k(a^k) \leq u^j(a^j) \)
Spot Market Approach

- **Switch** - Each link is a competitive market
- **User** - Seeks network resources
- **Network Broker (NB)** - Represents the user

**Unique Properties**
- Demand changes allowed
- Edge calculations
- Immediate availability

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Switches

- Bandwidth priced (non-storable resource)

- Each output link is an independent dynamic competitive market

- Price for link $i$ is determined using a modified tâtonnement process
  - Seeks equilibrium price
  - Allows demands to change dynamically
  - Stateless

- **Immediate availability and no reservation overhead**
Example Allocation and Prices

\[ p_{n+1}^i = p_n^i \cdot \frac{d_n^i}{\alpha \cdot s_i^i} \]

next price  current price  aggregate demand

link capacity
User

- Requires link bandwidth for their application
- Represented in the economy via a *Network Broker*

**User information**

- Bandwidth desired
- Budget $w^j$
- *QoS profile*, utility curve

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**QoS Profile**

- **Excellent**
- **Good**
- **Poor**

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Network Broker

- Agent for the user
- Located at the network edge
- Performs
  - CAC, policing, purchasing decisions
- It knows switch prices and user information
- Determines the amount of bandwidth to purchase

\[
\max \{ w^j (a^j) \}, \quad p^i \cdot a^j \leq w^j \implies a^j = \min_{i \in R^j} \left\{ \frac{w^j}{p^i} \right\}
\]
Spot Market Performance

Steady State (proofs)

- Achieves optimal and fair allocations
  - Pareto-optimal
  - Weighted max-min fair
  - Equitable, must distribute wealth appropriately

Algorithm 5.1

- Price equation always moves towards equilibrium

Network Dynamics (changing demands)

- Use simulation to measure performance
Spot Market ABR Rate Control

• RM-cells are used to obtain network feedback

Spot Market Approach

• Price is distributed using RM-cells

• A switch inserts the link price in the RM-cell if it is higher than what is currently stored.
ABR Simulation

Determine

• How *equitable* under dynamic conditions
  – Average QoS and % Good or Better (% GoB)

• Compare with *perfect* max-min and demand-based WMM

Simulation

• 152 users transmitting MPEG-compressed video traffic with random start times

• Two types of users *MoD* and *Teleconferencing*
Average % GoB

Average QoS Scores

Average QoS Scores for MoD Users

Average QoS Scores for Teleconferencing Users
# Spot Market Approach

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>• Distributed</td>
<td>• No guarantees</td>
</tr>
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<td>• Little a priori info required</td>
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<td>• Low implementation cost</td>
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<tr>
<td>Stateless &amp; simple calculations</td>
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</tr>
<tr>
<td>★ Efficient &amp; fair allocations</td>
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<tr>
<td>★ Calculation at network edge</td>
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<tr>
<td>★ Allows demand changes</td>
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<td>★ Immediate availability</td>
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Multi-Market Approach

*Two* markets per output link

- **Spot market** - Immediate availability
- **Reservation market** - Guaranteed bandwidth

**Unique Properties**
- Provides guarantees and immediate availability
- User can purchase from various markets
- User can modify choices as prices change
Reservation Market

- Bandwidth sold as an amount over time (segment)
- Switch will auction $\beta$ percent as reserved bandwidth
- Users bid for an amount of the next segment

- Any unused reserved bandwidth sold as spot bandwidth
User and The Multi-Market

- Must define QoS profile, \( w^j \), desired bandwidth
- Can purchase spot or reserved bandwidth

Indifference curve
Describes preferences for spot and reserved bandwidth
Can purchase *spot* and/or *reserved* bandwidth

Reservation bid based on
- Indifference curve
- Spot and reservation market prices
- Wealth

If not enough reserved bandwidth is purchased, then spot bandwidth is used for the remaining portion
Multi-Market Simulation

Demonstrate advantages of multi-market economy

- Seven link *parking-lot* network configuration
- Each link 45 Mbps, with segment length of 15 minutes
- Each user transmitted a MPEG-compressed video and were considered
  - Long-term (120 total)
    * 1/2 prefer reserved, remaining prefer cheaper
  - Short-term (40 total)
    * Prefer cheaper, cause sudden demand shift
Link 3 Bandwidth Allocation

- Maximum link capacity
- 90% of link capacity
- Total demand
- Total allocated
- Reserved allocated
- Reservation segment boundary

Link 3 Bandwidth Prices

- Spot market
- Reservation market
- Reservation segment boundary

Average QoS Scores

- Prefer cheaper
- Prefer reserved
## Multi-Market Approach

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<td>★ Immediate availability and guarantees</td>
<td>★ Guarantee duration</td>
</tr>
<tr>
<td>★ Users can purchase various types</td>
<td></td>
</tr>
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<td>★ Users can modify choices as prices change</td>
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Future Work

- Price-based routing
- Connection admission control
- Internet pricing
- Price-based security
- Users selling bandwidth