Resource Allocation and Pricing for QoS Management in Computer Networks

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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**

  Refereed publications - IWQoS'98, ICNP'98, ICATM'99

  Patents pending - US and Japan No. 08/971,127
- **Multi-Market Approach**

  Conference submission - EC'99

Multi-User Resource Allocation

Allocation Goals

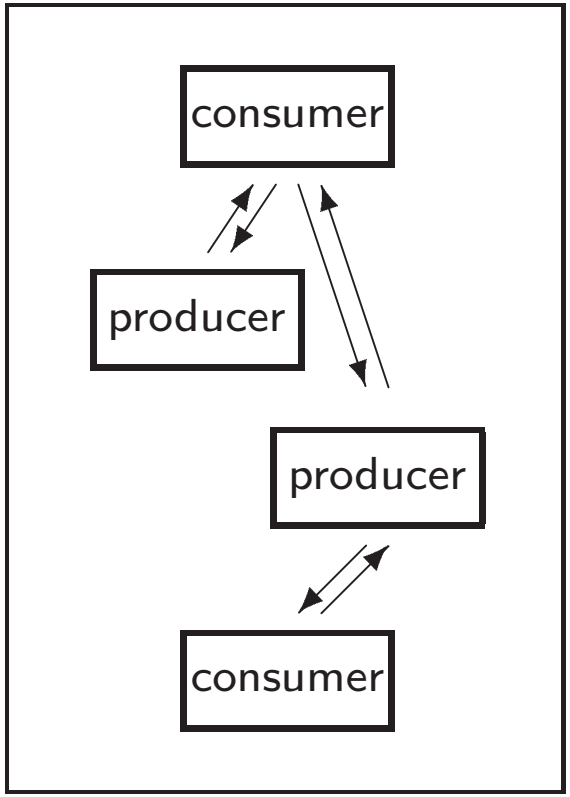
- *Efficient* - High utilization
- *Fairness* - Network and economic oriented

Allocation Classifications

- Centralized or distributed
- Static or dynamic
- Stateless or state-maintaining
- **Microeconomic-based**

Resource Allocation & Microeconomics

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

Method		Limitations
Constrained max.	Jiang [51]	centralized
ATM VC pricing	Ferguson [32]	CBR only
Eff. bandwidth	Kelly [55]	stat. models
Smart-market	MacKie-Mason [70]	implement.

Want a microeconomic-method that,

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

Competitive Market Model

Priced-based model proposed by Lêon Walras in 1874

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

Economy consists of multiple competitive markets

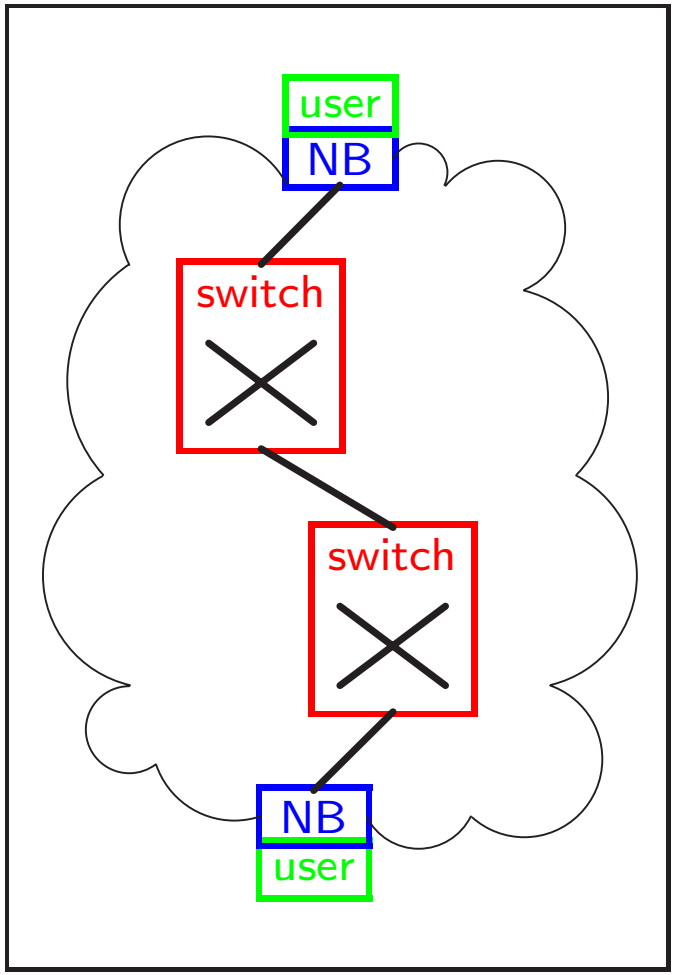
- Markets are separate and independent
- Consumers can participate in multiple markets
- Used in the *spot* and *multi-market* approach

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

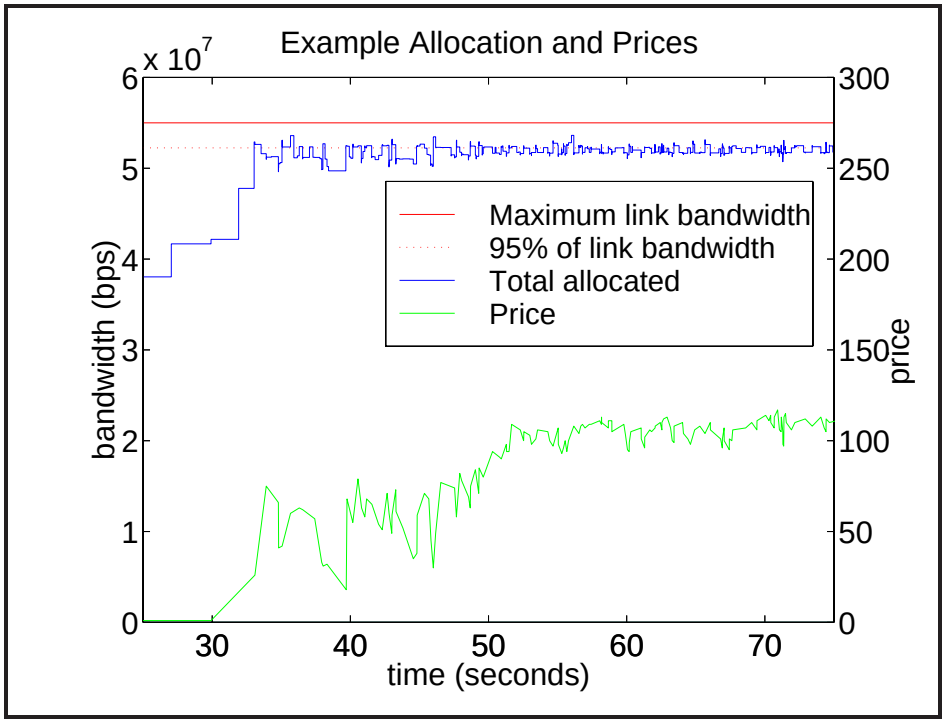
⋆ Demand changes allowed

⋆ Edge calculations

⋆ Immediate availability

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*



new price

current price

aggregate demand

$$p^i_{n+1} = p^i_n \cdot \frac{d^i_n}{\alpha \cdot s^i}$$

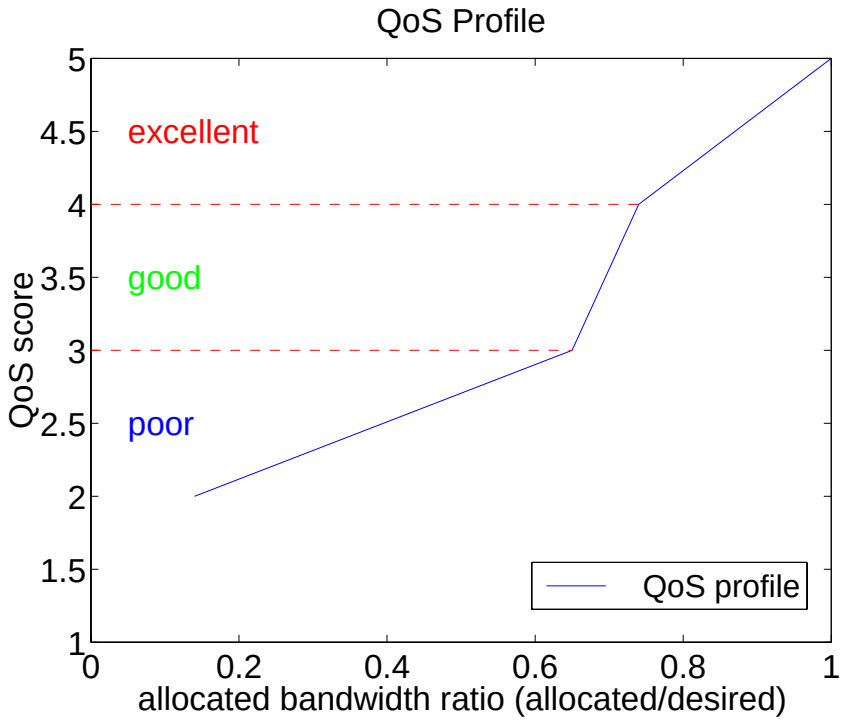
link capacity

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



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

$$\max\{u^j(a^j)\}, \quad p^i \cdot a^j \leq w^j \implies a^j = \min_{i \in R^j} \left\{ \frac{w^j}{p^i} \right\}$$

Spot Market Performance

Steady State (proofs)

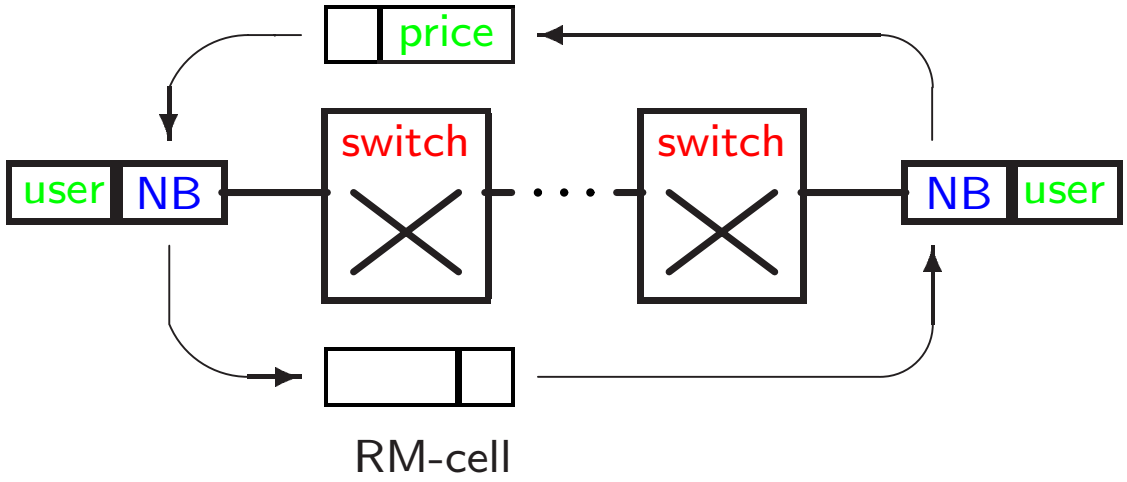
- Achieves *optimal* and *fair* allocations
  - Pareto-optimal
  - Weighted max-min fair
  - Equitable, *must distribute wealth appropriately* *Algorithm 5.1*
- Price equation always moves towards *equilibrium*

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.

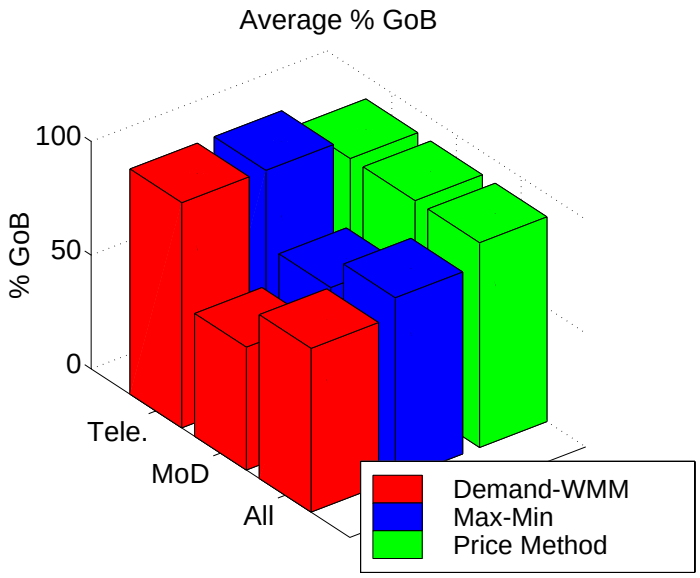
ABR Simulation

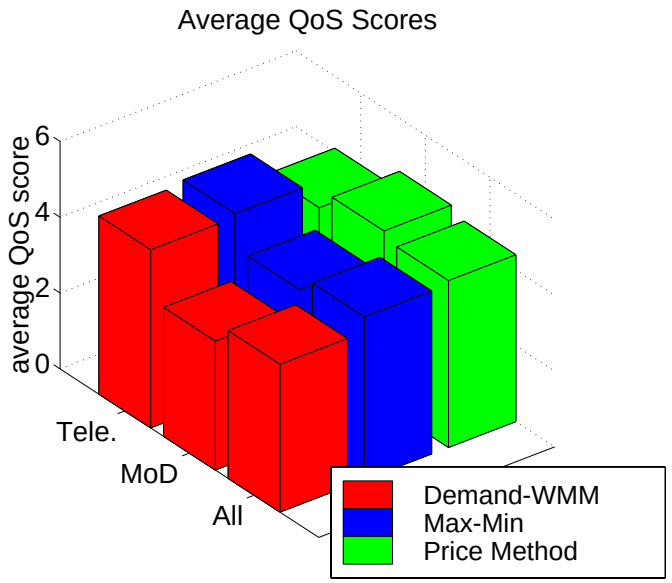
Determine

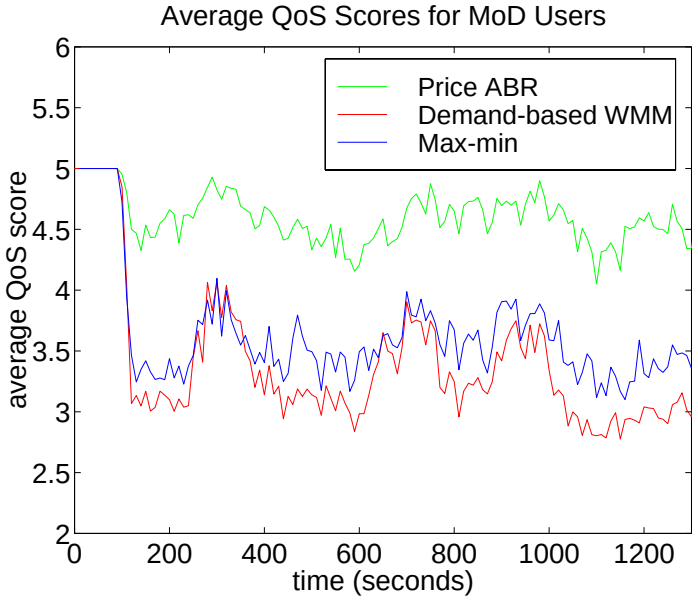
- How *equitable* under dynamic conditions
  - Average QoS and % Good or Better (% GoB)
- Compare with *perfect* max-min and demand-based WMM

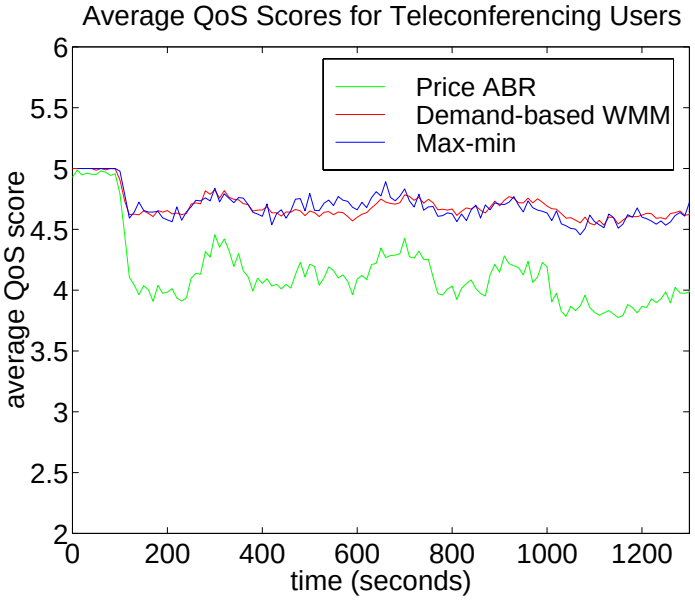
Simulation

- 152 users transmitting MPEG-compressed video traffic with random start times
- Two types of users *MoD* and *Teleconferencing*


Average % GoB
% GoB
100
50
0
Tele.
MoD
All
Demand-WMM
Max-Min
Price Method


Average QoS Scores
average QoS score
6
4
2
0
Tele.
MoD
All
Demand-WMM
Max-Min
Price Method


Average QoS Scores for MoD Users
average QoS score
6
5.5
5
4.5
4
3.5
3
2.5
2
0
200
400
600
800
1000
1200
time (seconds)
Price ABR
Demand-based WMM
Max-min


Average QoS Scores for Teleconferencing Users
average QoS score
6
5.5
5
4.5
4
3.5
3
2.5
2
0
200
400
600
800
1000
1200
time (seconds)
Price ABR
Demand-based WMM
Max-min

Spot Market Approach

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

Multi-Market Approach

Two markets per output link

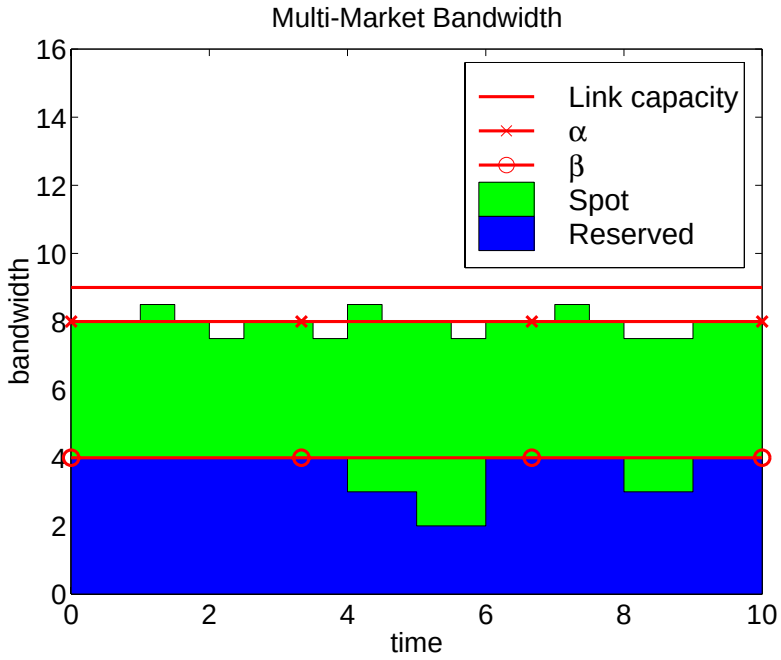
- **Spot market** - Immediate availability
- **Reservation market** - Guaranteed bandwidth

Unique Properties

⋆ Provides guarantees and immediate availability

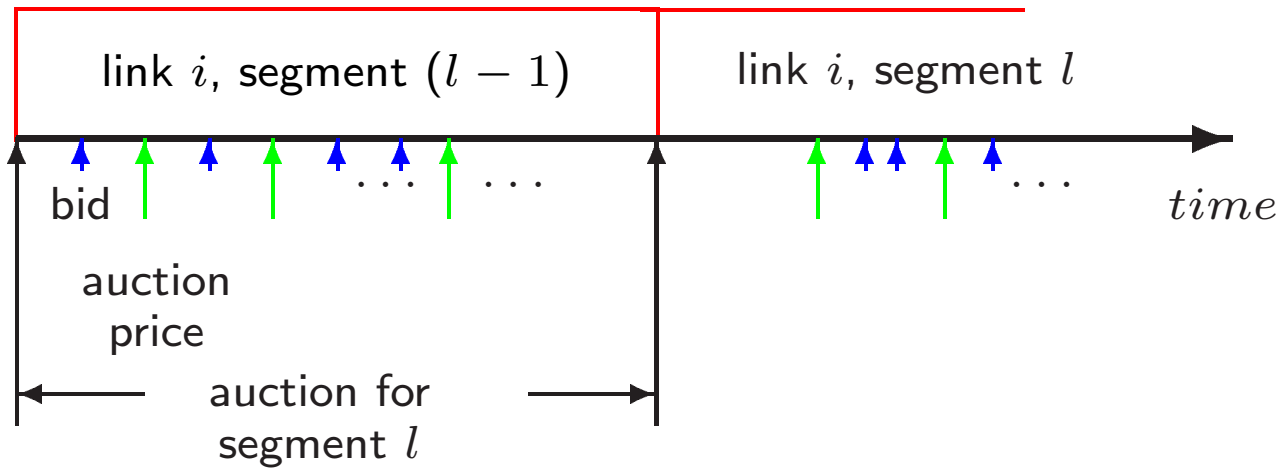
⋆ User can purchase from various markets

⋆ User can modify choices as prices change



Reservation Market

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



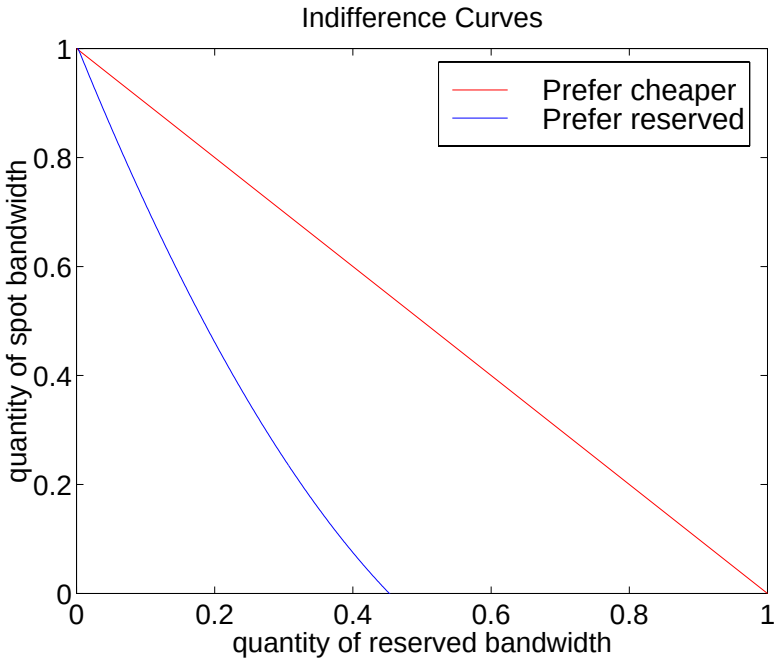
- Any unused reserved bandwidth sold as spot bandwidth

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

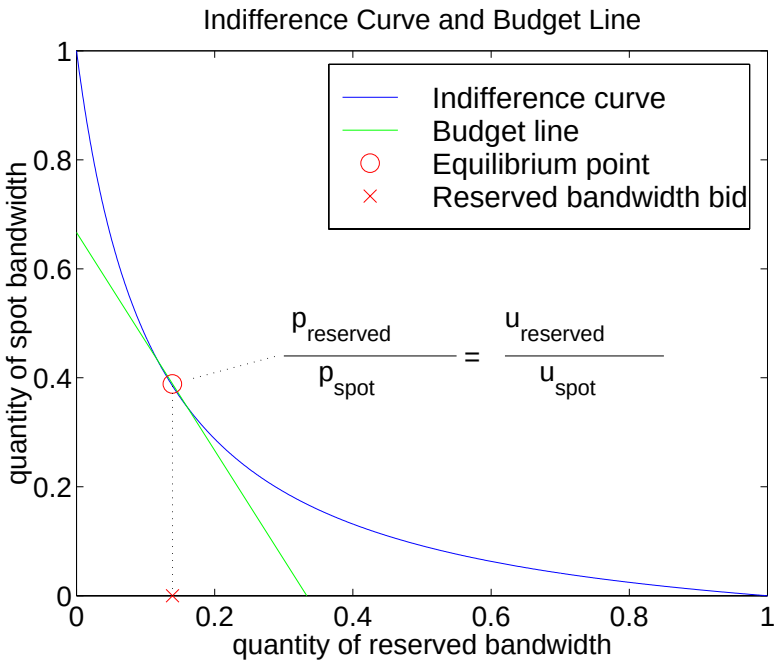


NB and The Multi-Market

- Can purchase *spot* and/or *reserved* bandwidth

Reservation bid based on

- Indifference curve
- Spot and reservation market prices
- Wealth

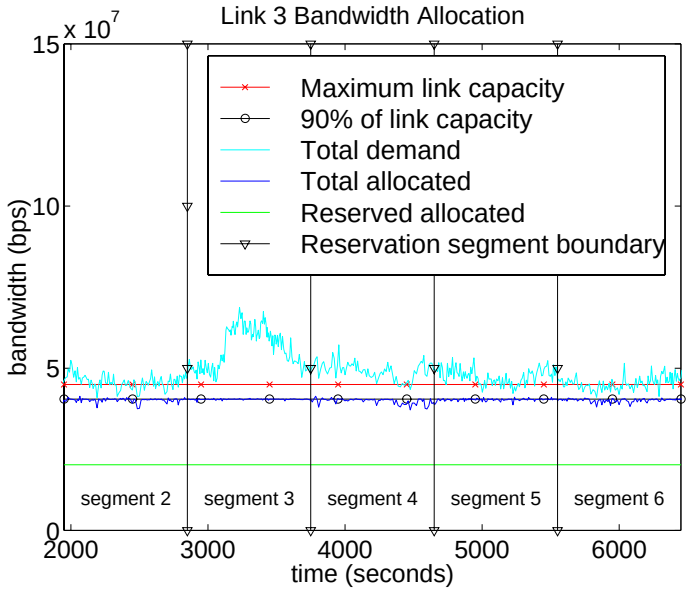


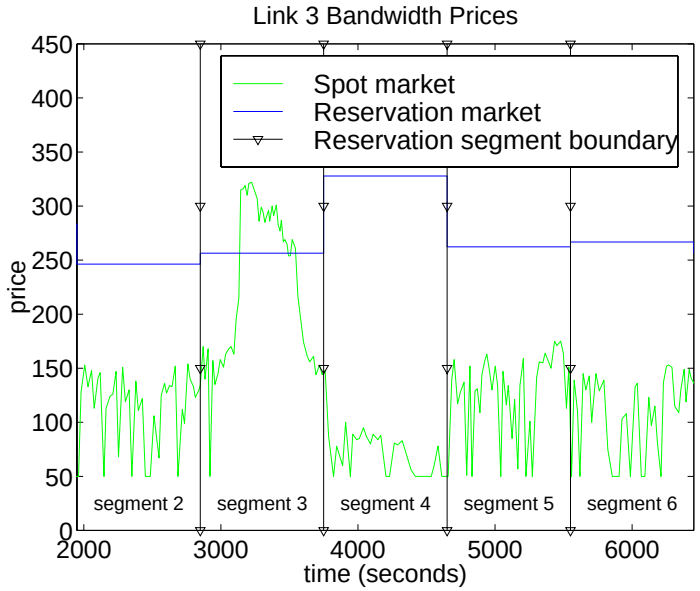
- If not enough reserved bandwidth is purchased, then spot bandwidth is used for the remaining portion

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
x 10^7
bandwidth (bps)
time (seconds)
Maximum link capacity
90% of link capacity
Total demand
Total allocated
Reserved allocated
Reservation segment boundary
segment 2
segment 3
segment 4
segment 5
segment 6


Link 3 Bandwidth Prices
price
time (seconds)
Spot market
Reservation market
Reservation segment boundary
segment 2
segment 3
segment 4
segment 5
segment 6


Average QoS Scores
average QoS score
time (seconds)
Prefer cheaper
Prefer reserved

Multi-Market Approach

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

Future Work

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