Integration of Pricing and Flow Control for ABR Services in ATM Networks

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Motivation

- ***"Best-effort"*** services have become widespread (e.g., Internet)
- ***Available Bit Rate (ABR)*** services intended for best-effort traffic and provide explicit congestion control signals
- Need for a ***theoretically justified*** and ***efficient*** scheme for pricing ABR services

Why price?

- Recover costs of network operation and maintenance
- Create revenue for network expansion
- Control congestion and distribute load
- Utilize network resources in an economically efficient manner

Economic theory suggests …

- Prices should reflect resources used => *usage sensitive* pricing
- *Usage prices* should reflect *congestion*
  - no congestion => zero usage costs
  - congestion => non-zero usage costs
- *Optimal* pricing must be weighed against *efficient* implementation

What do we price?

Effects of congestion

- Increased per packet delay/jitter
- Decreased throughput

Best-effort service performance

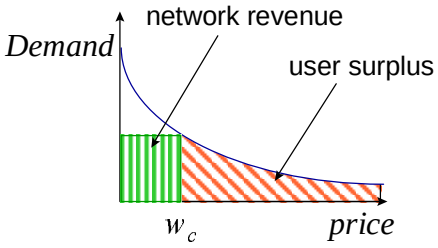
- Performance of best-effort services is *transfer delay* of files, images, web pages, etc.
- *Delay* is inversely proportional to available bandwidth => *price bandwidth*

Pricing scheme features

- Charges computed at the *network access point*, in *fixed intervals* based on *prices posted* by network
- Price of bandwidth is the *sum* of the price of bandwidth on *all links* along a connection's route
- Prices depend on *demand*
- Prices are adjusted *locally* (decentralized) at each switch in an *iterative* fashion

Social welfare optimization

Welfare = network revenue + user surplus



- The *equilibrium price=supply* operating point which *maximizes network revenue* also *maximizes welfare* and

$$w_c = \sum_{l \in R_c} a_l, \qquad a_l (C_l - \sum_{c: l \in R_c} D_c(w_c)) = 0$$

Decentralized & iterative pricing

- *Decentralized* pricing, each link updates prices independently:

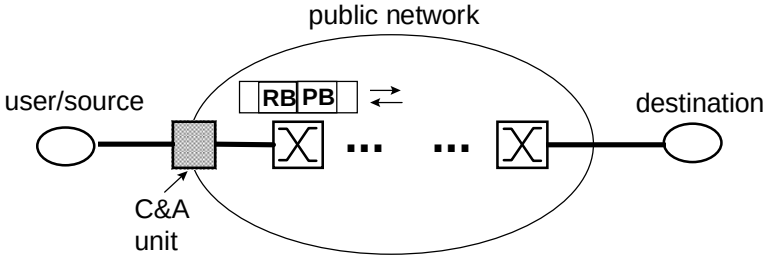
$$\text{if } \sum_c D_c < C_l \text{ then decrease } a_l$$
$$\text{if } \sum_c D_c > C_l \text{ then increase } a_l$$

- *Iterative* price updates:
  1. network posts prices
  2. users place demands
  3. network checks demand & updates prices

ABR congestion control

- *Closed loop* & *rate-based* congestion control (*ATM Forum Traffic Management 4.0)*
- *Resource Management (RM) cells* contain a *Congestion Indication (CI) bit* and *Explicit Rate (ER) field*
- Source behavior:
  - periodically sends RM cells
  - additive increase/multiplicative decrease depending on CI bit in received RM cell
  - sending rate is always less than ER in the received RM cell

Utilizing the congestion control loop



- Two fields are added in RM cell:
  - "RB" field for Requested Bandwidth
  - "PB" field for Price/unit of Bandwidth/unit of time
- Charging & accounting unit: $\text{Charge} = \sum_{n=1}^{k} w^n \cdot V^n$

Price updates

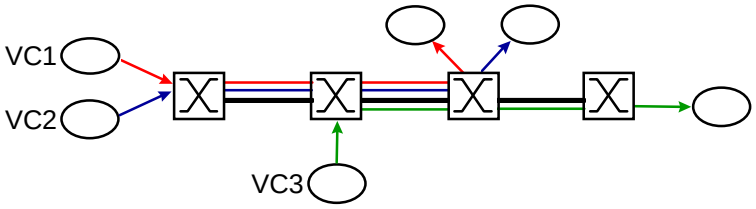
- Prices updated in intervals $n=1,2,3\ldots$, of length T
- D_c^n: connection c's bandwidth demand at interval n
- a_l^n: price at link l in interval n
- Price update (at each link l):

$$a_l^n = \begin{cases} \max\left\{a_l^n - \dfrac{h a_l^n}{C_l}\left(C_l - \sum_c D_c^n\right), 0\right\} & a_l^n \neq 0 \\ \max\left\{\dfrac{k}{C_l}\left(C_l - \sum_c D_c^n\right), 0\right\} & a_l^n = 0 \end{cases}$$

- Values used for h, k are $h \leq 1, k = 0.05$

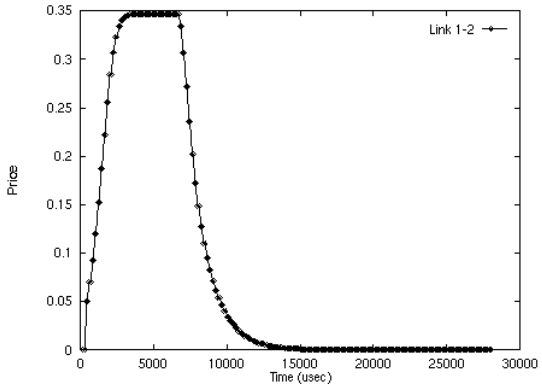
Simulation objectives and set-up

- Objectives:
  - effect of pricing scheme on flow control
  - transient behavior of pricing scheme



- Link distances: 1km, 100 km, and 1000 km
- Considered "greedy" sources

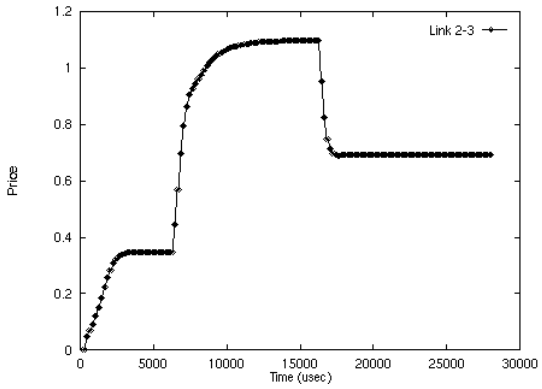
Simulation results: 1 km links



- h=0.4, k=0.05
- Charging interval: 200 μs
- VC1, VC2 on at 0 ms
- VC3 on at 6 ms
- VC1 off at 16 ms

➜ convergence in ≅ 4 ms

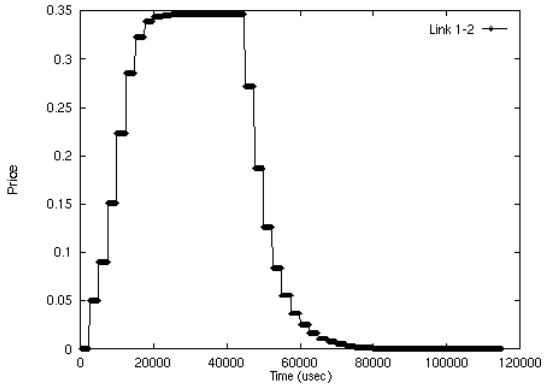
Simulation results: 1 km links



- h=0.4, k=0.05
- Charging interval: 200 μs
- VC1, VC2 on at 0 ms
- VC3 on at 6 ms
- VC1 off at 16 ms

➜ convergence in ≅ 4 ms

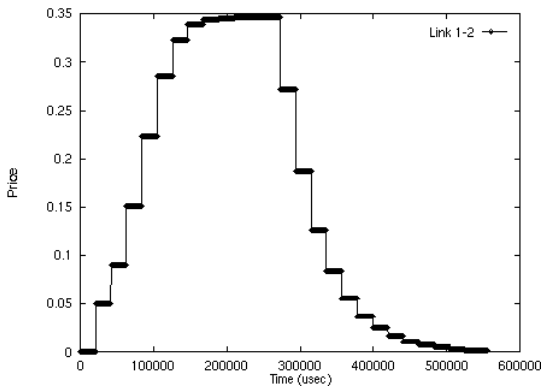
Simulation results: 100 km links



- h=1, k=0.05
- Charging interval: 2.5 ms
- VC1, VC2 on at 0 ms
- VC3 on at 40 ms

➜ convergence in ≅ 20 ms

Simulation results: 1000 km links



- h=1, k=0.05
- Charging interval: 21 ms
- VC1, VC2 on at 0 ms
- VC3 on at 250 ms

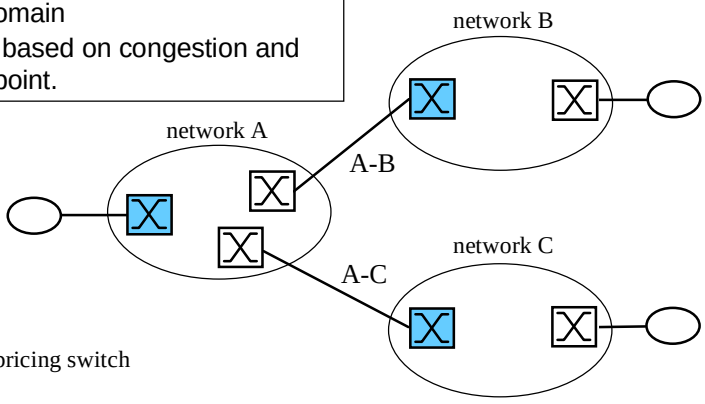
➜ convergence in ≅ 200 ms

Simulation results

- Convergence of flow control is not affected
- Prices converge reasonably fast
  - # of iterations depends on *h* and are independent of RTT
- Larger RTT => longer convergence times
  - however, more traffic aggregation occurs in WANs => smaller and less frequent traffic changes

Interconnected networks

- prices are non-zero only for congested links
- one pricing switch can be responsible for setting prices for resources of a network domain
- prices are based on congestion and entry/exit point.



What about MCR>0

- MCR: Minimum Cell Rate at which a source can always send data
- MCR+x=15+5=20 is *not the same* as 5+15=20 !
- Performance of ABR service not only total bandwidth, but total bandwidth *and* MCR (some form of guarantee)
- Pricing model is linked with bandwidth allocation algorithm
- Currently being studied !

Summary

- We have presented a pricing scheme for ABR services in a multiple resource (links) environment which is *theoretically sound*
- ... *utilizes* ABR congestion control mechanisms (no additional communication overhead)
- ... *integrates* flow control and pricing
  - flow control => prevents congestion
  - pricing => economically efficient resource utilization.
- Simulations show no negative effect of pricing on flow control and that prices converge reasonably fast
- For MCR>0 pricing model interlinked with bandwidth allocation