A Smart Market for an Integrated Services Network



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Internet Failure: Where is Multiple QoS?

- Remarkable application model: "blind" transport on which end-users build applications
- "Remarkable" transport model:
  - bread lines
  - Any color you want as long as it's brown
- Why can't Internet grow up?
  - Want: Video, audio, collaborative workspaces
  - Have: static text and graphics (plus ads!)

Problems with various approaches

- Fixed application types
- Fixed service prices
- Vs. rich heterogeneity of service qualities
  - bandwidth
  - mean delay
  - delay jitter
  - packet loss
  - max delay
  - &c

My approach

- 1. Reserve effective bandwidth in advance
- 2. Simultaneously solve routing problem
- 3. Use revelation mechanism for heterogeneity
- Advantages:
  - fully general, multidimensional
  - 2-dimensional scaling: problem size and time horizon
  - responsive to heterogeneity, irregularity and surprise

Effective bandwidth

- Curse of dimensionality:
  - K service quality characteristics
  - N service nodes
- Managing the problem
  - Collapse K characteristics to 1: effective bandwidth
  - Waste some bandwidth to buy some service quality differentiation with guarantees
  - Use time to spread out computational complexity: shrink intervals as computation improves

Routing problem

- network technology
  - handles: multiple nodes; fixed capacity links; packets or cells
  - needs: protocol for directed path bandwidth reservations (ATM, RSVP)
- multi-commodity flow problem:

$$\max_{d_{pk}, f_{ij,pk}} \sum_{p \in P, k \in K} u_{pk}(d_{pk}) - c_{ij,pk} f_{ij,pk}$$

$$\text{subj. to} \sum_{j \neq i} f_{ij,kp} - \sum_{j \neq i} f_{ji,kp} = \begin{cases} d_{pk} & \text{if i is p's origin} \\ -d_{pk} & \text{if i is p's dest} \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{k} b_{ijk} \left(\sum_{p} f_{ij,pk} \right) \leq B_{ij} \quad \forall i \neq j$$

Characterizing solution: nodal prices

- management strategy:
  - admission rule (which flows with what characteristics?)
  - routing plan (which resources do they get?)
- once network is optimally routed, transport prices are:

$$c_{OD} = \pi_O - \pi_D + w_{OD}$$

System cost = insertion price - extraction price + congestion fee

Market solution?

- Decentralize by setting nodal spot prices equal to π_{ipk}
- BUT: finding optimal π_{ipk} requires solving full central planning problem, with knowledge of true user benefit functions
- Congestion externality is core problem: When capacity binding, need to know the (user) value of the next best use of the capacity

Generalized Vickrey Auction

- Objectives:
  - efficiency (revelation)
  - individual rationality
  - budget balance
- Varian & MacKie-Mason (1994): Groves mechanism for:
  - multiple units
  - multiple goods
  - externalities

Generalize Vickrey Auction II

- Agents announce preferences and types
- Auction:
  - solve allocation optimization
  - pay each agent the incremental surplus she creates for others by her participation
  - truthtelling is dominant strategy
- Problems: In general, can only have 2 out of 3 desiderata

MARX
(Michigan Adaptive Resource Exchange)

- Real-time information network resource allocation system
  - Mechanism architectures, bidding protocols, service description language
  - Focus on efficient management and flexible response to disruption
- Working code, testbed demos, simulations and lab experiments