Addressing resource allocation problems for communication networks using Microeconomics:

An introduction

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Why resource management ?

- Land – Build multi-stories
- Water – Collect rain waters
- Electricity – Use alternative sources of energy
- Paper – Recycle papers
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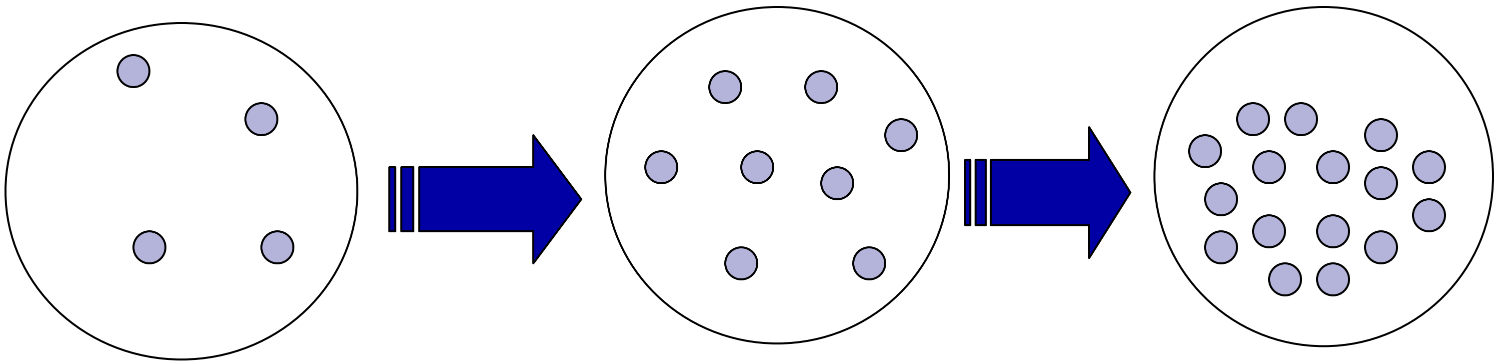
Scarcity of communication resources



Growth in the size of communication networks

- Bandwidth, data rate, link capacity
- Buffer capacity at routers
- Power consumed by the devices
- Modulation/demodulation schemes
- Coding-decoding schemes

- Scarcity of resources puts constraints over the use of a network
- Calls for optimal resource management

Challenges for developing future standards

- Size of the network
- Information decentralization: Nobody in the system has complete information about the network
- Types of services offered by the network is large
- The Quality of Service (QoS) associated with each service varies
- In a large network centrally controlled resource management requires added infrastructure and increases network vulnerability
  - Distributed schemes are preferred

Microeconomics provides tools

- Decentralized resource allocation has been extensively studied

Example

- Competitive market
  - Users submit their individual ***demand/supply curves***
  - They don't know other users' demands/supplies
  - The final allocation of goods determined by equilibrium market price is the optimal allocation corresponding to an equivalent centralized system.

Microeconomics provides tools (cont')

Decentralized resource allocation

Mechanism Design

- A system with decentralized information
- Users need to communicate: Specify a communication language
- Iterative process should converge to an equilibrium
- Specify an allocation rule based on equilibrium messages
- Goal: To achieve an allocation that is optimal for an equivalent system with centralized information

Unicast with routing and QoS provisioning:
A pricing perspective

The model

- Set of users: $\mathbf{N} = \{1, 2, ..., N\}$
- Set of types of services requested by user $i \in \mathbf{N}$ is $\mathbf{M}_i$
- QoS desired for each $i \in \mathbf{N}$ and $j \in \mathbf{M}_i$ is f_{ij}
- User i's preference: ***Utility function*** $U_i(x^i), \quad x^i \in R_+^{|M\_i|}$

- Set of links: $\mathbf{L}$
- Set of resources on link l, $l \in \mathbf{L}$, $\mathbf{K}_l$
- Amount of resources: $c_{\mathbf{K}}$
- Topology of the network: $\mathbf{T_L}$
- Possible routes for service delivery: $\mathbf{R_{T_L}}$
- Set of resource allocations along all possible routes for $j \in \mathbf{M}_i$ and $i \in \mathbf{N}$ that guarantee the end to end QoS f_{ij} -- $\mathbf{F}_{ij}(\mathbf{R_{T_L}}, \mathbf{K})$
- Set of resource allocations along route $t \in \mathbf{R_{T_L}}$ for $j \in \mathbf{M}_i$ and $i \in \mathbf{N}$ that guarantee the end to end QoS f_{ij} -- $\mathbf{F}_{ijt}(\mathbf{R_{T_L}}, \mathbf{K})$

Unicast with routing and QoS provisioning: (cont')

Objective: (The centralized problem)

P $$\max_{x,\mathbf{R}_{\mathbf{T_L}}} \sum_{i \in \mathbf{N}} U_i(x_i)$$

subject to

P.a $$x^i \in R_+^{|M\_i|}$$

P.b $$r^{i,j} \in \mathbf{F}_{ij}(\mathbf{R}_{\mathbf{T_L}}, \mathbf{K})$$

P.c $$\sum_{i \in \mathbf{N}} \sum_{j \in \mathbf{M}_i} x_j^i r_{l,k}^{i,j} \le c_{l,k}$$

Unicast with routing and QoS provisioning: (cont')

Solution: A market mechanism

1) The auctioneer announces prices $\lambda_{l,k}$ for the resources at each link of the network. The users announce their desired QoS f_{ij} to the service provider.
2) Based on these announcements the service provider computes,
   i. the allocation along route t that results in minimum price per unit of service,

$$r^{i,j,t}(\lambda) \in \arg\min_{r^{i,j,t} \in \mathbf{F}_{ijt}} \sum_{l \in V_{ijt}} \sum_{k \in \mathbf{K}} \lambda_{l,k} r_{l,k}^{i,j,t}$$

   ii. the minimum price per unit of service for route t

$$p_{j,t}^{i}(\lambda) = \sum_{l \in \mathbf{V}_{ijt}} \sum_{k \in \mathbf{K}} \lambda_{l,k} r_{l,k}^{i,j,t}$$

   iii. finds the route with minimum price and the corresponding price

$$p_{j}^{i}(\lambda) = \min_{t \in \mathbf{T}^{i,j}} p_{j,t}^{i}(\lambda)$$

Unicast with routing and QoS provisioning: (cont')

3) Based on the price the users demand the connections determined by,

$$x^i(p) \in \arg\max_{x^i \in R_+^{|M-i|}} \left[U_i(x^i) - \sum_{j \in \mathbf{M}_i} x_j^i p_j^i(\lambda) \right] \quad \forall i \in \mathbf{N}$$

4) The auctioneer re-computes the price based on the aggregate access demand,

$$z_{l,k}(\lambda, t) = \sum_{i \in \mathbf{N}} \sum_{j \in \mathbf{M}_i} \left(x_j^i(\lambda) r_{l,k}^{i,j,t}(\lambda) \right) - c_{l,k}$$

5) If $z(\lambda) \leq 0$ the process ends, otherwise the auctioneer updates the price based on Scarf's algorithm.

Result

The above market mechanism achieves the solution of the centralized resource allocation problem **P.**

Other examples of resource allocation problems

Multirate multicast problem → Public goods

Power allocation in presence of interference → Economies with externalities

Summary

- Microeconomics provides theoretical tools for studying decentralized resource allocation problems for communication networks.
- The models that have been investigated so far are very simple and abstract.
- There is a scope of tremendous research to understand complicated, more realistic network models. There needs to be done a lot to bridge the gap between theory and implementation.

Reference

- T. Stoenescu and D. Teneketzis, “Decentralized resource allocation mechanisms in networks: realization and implementation”, *Advances in Control, Communiation Networks, and Transportation Systems,* in honor of Pravin Varaiya, pp 225-263, 2005.

Thank You !

Questions ?