Outline

- Economics of Networks
- 802.11 WLANs
- Sensor Networks
- Congestion Control
- Traffic Models
Economics of Networks

Outline

- Hangover
- Pricing of Services
- Competition of Users
- Competition of Providers

Suggested Readings:

- http://www-inst.eecs.berkeley.edu/~228a/papers/telecomRevolution.htm
- http://info.isoc.org/internet-history/
- http://www.sims.berkeley.edu/resources/infoecon/Networks.html
Economics of Networks

Hangover

Bubble: Wired
Economics of Networks

Hangover

Bubble: Wireless
Economics of Networks

Hangover

- **Over-Investment**
  - Based on unrealistic growth forecast
  - Overcapacity: Fiber → 5x100 in three years
  - Too many companies competing for same market

- **Debt**
  - Wireless: Expensive spectrum licenses
  - Fibers
  - IT in companies: PCs, Servers, Networks

- **Fraudulent Claims**
  - WorldCom, Global Crossing, Enron
Economics

Key Ideas

- Value of services to users: externality, QoS, CoS
- Market segmentation
- Flat rate pricing; congestion pricing; Paris metro pricing; time-of-day pricing
- Incentive compatibility
- Inter-ISP settlements; Peering agreements
- Internet as a public good
Economics

Value of Services

- Externality: Kazaa
- Value per bit: email vs. fax vs. picture
- Value of bit rate: video stream vs. radio
- Value of low latency: video stream vs. video conference
- Value of low response time: browsing with DSL vs. browsing with 56k
- QoS affects value and usage
- Value of QoS depends on application, user

Question: How do you define/measure value?
Economics

Market Segmentation

- Businesses vs. Residential Customers
- Network Application Providers vs. public Web Sites
- Principle: Charge more users with higher utility
- Question: What makes segmentation possible? What limits it?
Economics

Differentiated Pricing

Examples:

- First Class & Economy in plane: More space but much more expensive
- Paris Metro: More expensive $\rightarrow$ Fewer Users $\rightarrow$ Better Service (e.g., Stanford vs. Berkeley?)

Suggests Class of Service:

- Better service by mechanism: e.g., priority
- Better service by fewer users: e.g., expensive network; congestion pricing (e.g., packet marking); time-of-day

Alternative: QoS: You know what you pay for

- Service Level Agreement (implementation?)
- QoS of accepted calls: end-to-end test

Question: How would you price a product whose quality varies statistically?
Economics

Incentive Compatibility

How to discover the user’s willingness to pay?

Examples:

- California Electricity: Providers offer bids and CA buys cheaper first \( \rightarrow \) prices escalate
- Highest bidder auction: Spectrum auctions
- Highest gets but two highest pay
- Second highest price: Incentive compatible

Question: Is TCP incentive-compatible?
Economics

Competition

- Basic supply and demand:
  - More capacity than traffic $\rightarrow$ prices drop and providers go bankrupt; recovering fixed costs

- Internet traffic doubles every year instead of every 100 days ….

- Quality service is still rare and valuable:
  - Businesses use video conference over ISDN
  - Users pay a lot for CATV and pay-per-view
  - T1 service expensive: demand exists

- Question: What is the role of state regulation?
Economics

Game Theory

- Framework to analyze result of interaction of self-interested agents
- Suggests strategies for
  - Pricing services
  - Peering agreements
  - Routing
  - QoS definitions
  - Evolution of industry (e.g., consolidation vs. specialization)
- Two parts: Games & Mechanism Design
802.11 Wireless LANs

- We will explore
  - Physical Layer
  - Medium Access Control
  - Security Issues
  - Quality of Service Issues
802.11 Wireless LANs

Overview

- Sometimes referred to as Wireless Ethernet or Wi-Fi networks

<table>
<thead>
<tr>
<th>Key Standards</th>
<th>Max Rate</th>
<th>Spectrum</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>2 Mbps</td>
<td>2.4 GHz</td>
<td>1997</td>
</tr>
<tr>
<td>802.11a</td>
<td>54 Mbps</td>
<td>5 GHz</td>
<td>1999</td>
</tr>
<tr>
<td>802.11b</td>
<td>11 Mbps</td>
<td>2.4 GHz</td>
<td>1999</td>
</tr>
<tr>
<td>802.11g</td>
<td>54 Mbps</td>
<td>2.4 GHz</td>
<td>2003</td>
</tr>
</tbody>
</table>

Factors such as cost of deployment/maintenance and end-user flexibility are fueling phenomenal growth.
802.11 Wireless LANs

Physical Layer: Key technologies are
- Frequency Hopping Spread Spectrum
- Direct Sequence Spread Spectrum
- Orthogonal Frequency Division Multiplexing

Medium Access Control (MAC)
- Based on Carrier Sense Multiple Access (CSMA)/Congestion Avoidance (CA)
802.11 Wireless LANs

Security Issues
- Basic security using the Wired Equivalent Privacy (WEP) standard based on Symmetric Key cryptology
- 802.1x attempted to rectify the serious flaws of WEP using stronger authentication

Quality of Service
- How to introduce QoS notions in an inherently non-guaranteed service?
- Basic idea: Service prioritization using different length of medium access deferral for different classes
802.11 Wireless LANs

Research issues of interest in this course

- Analytic and simulation based modeling for
  - Parameter tuning
  - Performance prediction
  - Impact of specific protocol features

- Performance offered to upper layer protocols (e.g., TCP)

- QoS differentiation and impact on various data, voice, and video applications
  - Investigate 802.11e (standardization in progress)

- Evaluation of various fairness criteria
Sensor Networks

- Ad hoc multihop networks
- Sensor nodes perform
  - Sense local environment
  - Communicate own observations
  - Relay messages from others
Sensor Networks
Research issues of interest in this course

- Evaluation of various routing schemes
  - Scalability with number of nodes
  - Convergence time
  - Robustness to topology changes including failures
  - Energy efficiency
  - Application level performance

- Localization, failure detection

- Application-specific Sensor Network strategies (e.g., PEDAMACS)
Congestion Control

Outline

- Motivation
- Examples
- Issues
Congestion Control

Motivation

- At user level: Issues with QoS
- At network level: Losses, inefficiency, unfairness
- At switch level: Scalability problems
Congestion Control

Examples

- TCP
- Congestion in routers
- Call Admission Control
Congestion Control

Issues

- Fairness vs. Optimality
- Simplicity
- Robustness
Traffic Models

Outline

- Why bother?
- Transactions
- Packet flows
Traffic Models

Why Bother?

- Network should be robust; not based on detailed traffic assumptions
- Traffic characteristics impact
  - Effectiveness of multiplexing
  - Buffer sizes required
  - Time scale of bandwidth allocations
Traffic Models

Transactions

File transfers:
- File sizes: Heavy tailed
- Timing of requests: Poisson
- Geography:
  - Kazaa – poor locality
  - Akamai – improved locality

Other applications:
- video conferences
- VoIP
Traffic Models

Packet Flows

♦ Self-Similarity:
  - Heavy Tail + TCP → Self Similar Flows
  - Heavy Tail Files + Structure of Web Sites → Self Similarity

♦ Relevance:
  - Not obvious – a matter of time scale