NETWORK DESIGN

- design choices
- queueing theory
- business factors

Network Strategy

**Business factors:**
- business nature
- organization
- IT architecture
- planning horizon

**Design choices:**
- technology
- topology
- capacity
- provider
- geography

**Benefits:**
- quality
- redundancy
- flexibility

Design Choices

- technology
- topology
- capacity
- provider -- public / private network
- geography
Topology

• single vs multi-layer network
  – number of nodes
  – number of paths
• hub / switch locations
• paths

Geography

• technology
  – availability
  – quality
  – supporting services
• regulation
  – monopoly/competition
• cost

Capacity: Queueing Theory

• demand is uncertain
• capacity is costly
• A/B/c/K/p
  – arrival distribution
  – service distribution
  – number of servers
  – buffer size
  – population
M/M/1 Model: Assumptions

- exponential distribution of time between arrivals ($A = M$): mean time between arrivals = $1/\lambda$
- exponential distribution of service time ($B = M$): mean service time = $1/\mu$
- $c = 1$ server
- $K = $ unlimited buffer
- $p = $ infinite population

M/M/1: Exponential Distribution

$f(t) = \lambda e^{-\lambda t}$
$E(t) = 1/\lambda$
$V(t) = 1/\lambda^2$

M/M/1: Performance Measures

- utilization rate, $\rho = \lambda/\mu$
- number of jobs in queue, $L_q = \rho^2/[1-\rho]$
- number of jobs in system (in queue or process), $L = \rho/[1-\rho]$
- Little's Formula
  - average waiting time, $W_w = L_w/\lambda$
  - average waiting & service time, $W = L_w/\lambda + 1/\mu = 1/(\mu-\lambda) = L/\lambda$
M/M/1: Example

- mean time between arrivals = 500 ms
- mean service time = 475 ms
- utilization = ...
- average time = ...
- If reduce service time to 400 ms, what is effect on average time?

M/M/c/c (Erlang B)

<table>
<thead>
<tr>
<th>Channels</th>
<th>Probability of blocking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.01%</td>
</tr>
<tr>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>10</td>
<td>2.26</td>
</tr>
<tr>
<td>15</td>
<td>4.78</td>
</tr>
<tr>
<td>20</td>
<td>7.70</td>
</tr>
</tbody>
</table>

Aggregation

- How to plan for larger scale of traffic?
- Contrasting views:
  - smoothing
  - fractal
Packet-Switched Network: Kleinrock Approximation

- if
  - packet lengths are exponentially distributed
  - arrivals of new packets at each node are independent Poisson processes
  - service times are independent
- Then queues are independent M/M/1
  - numbers of packets and delays are independent

More General Models

- non-exponential arrival
- non-exponential service
- multiple servers
- limited buffer
- varying customer population

Capacity: Decision Variables

- server capacity
- buffer capacity
- compare:
  - impact on average waiting & service time
  - marginal cost
Redundancy

- service providers
- paths
  - physical route
  - cable / satellite
- pricing basis
  - subscription
  - usage

Singapore-Japan: Physical Route

- until 2001, only one link (APCN1) – so, Sept 1999 Taiwan earthquake disrupted communications
- subsequently, additional 10Gbps link (APCN2)

Case: AT&T Network Design

- switch – dual processor
- signal transfer points
  - deployed in pairs
  - each at 50% capacity
- network control points
  - dual processors
  - back ups
- power supply: battery back-up
Flexibility

- private vs public network
- fixed line vs wireless
- commitments vs options
- pricing basis

Case: Pier 1 Imports

<table>
<thead>
<tr>
<th>Business unit</th>
<th>Telecommunications service</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 zone offices, distribution center</td>
<td>AT&amp;T frame relay + ISDN back-up</td>
</tr>
<tr>
<td>32 regional offices</td>
<td>AT&amp;T frame relay with no back-up</td>
</tr>
<tr>
<td>730 retail stores</td>
<td>Sprint frame relay</td>
</tr>
</tbody>
</table>

Business Factors

- business nature
- organization
- IT architecture
- planning horizon
Business Nature

- service
  - information
  - transaction
- data flows
  - symmetric
  - asymmetric

Case Study: Distance Education

- downlink from provider to student
  - multimedia
  - not interactive
  - same for all students
- uplink from student to provider
  - interactive
  - must be individual

Organizational Parameters

- organization
  - acceptance of change
  - risk tolerance
- human resources
- finances
IT Architecture

- processing
- software
- databases

Planning Horizon

- business growth
  - volume of communications
- international expansion
  - volume of communications
  - geographical coverage
- maturity of technology

Case: India’s Stock Exchanges

- Bombay Stock Exchange (BSE): telephone trading
  - long waiting lists for service
  - unreliable
  - high prices for long distance
  - Insat-2D satellite connexion
  - 1997: NSE daily volume reached US$500 million, eclipsing BSE with $300 million