EL736 Communications Networks II: Design and Algorithms

Class1: Introduction
Yong Liu
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From Telephone Networks to Data Networks

- voice calls vs. datagrams
- circuit switching vs. packet switching
- multiplexing/de-multiplexing at edge, shared network core
Network Service Providers

- multiple autonomous systems (ASes) managed by different network providers
- peering at gateway routers
- dealing with network design within one admin. domain
Traffic Networks vs. Transport Networks

- Traffic Networks: provide application services to end users
  - the Internet
  - telephone networks
  - private networks
- Transport Networks: provide physical facility to transport traffic for customer networks
  - setting up leased circuits/trunks (semi-)permanently
  - SONET, WDM, cross connects

FIGURE 17 An Administrative Domain Using Multiple Transport Providers

FIGURE 18 Multiple Service Networks Over One Transport Provider
Network Resource & Cost

- link capacity (bps, pps)
- router/switch
  - memory (bytes)
  - processing power (CPU, Hz)
- network cost:
  - provisioning cost ($, hours)
  - operational cost ($, hours)
Network Demand

- traffic characteristics
  - how much? point to point traffic volume
    - stationary+stochastic
  - + where? traffic demand matrix
- different natures for different networks
  - the Internet: packets
  - telephone network: calls
  - transport network: circuits
- demand of traffic networks generated by end users
- demand of transport network generated by its customer traffic networks
Traffic Demand in Internet

- bits, bytes, packets/second
- very “random”
  - controlled by end-users and protocol behaviors
  - highly variable, bursty, long-range-dependent, self-similar, ...
  - predictable? reasonable models?
- characteristics on a single link
  - packet arrival process: approximately Poisson :) 
  - packet size distribution: non-exponential :(  

Packet Delay on a Single Link

- **M/M/1 Approximation:** \( D(\lambda_p, \mu_p) = \frac{1}{\mu_p - \lambda_p} = \frac{1/\mu_p}{1 - \rho_p} \)
- Packet delay on a T1 (1.5Mbps) link
- Benefit of multiplexing
  - Ten 1.5Mbps links vs. one 15Mbps link

![Graph showing packet delay vs. link utilization](image)
Traffic in Telephone Network

- circuit switching
  - calls blocked if no available circuit
- call arrivals approximately Poisson :) 
- call duration approximately exponential :) 
- offered load unit -- Erlang: \( \alpha = \lambda_t \times \tau_t \)
- call blocking probability
  - Erlang-B loss formula \( B(\alpha, c) = \frac{\alpha^c / c!}{\sum_{k=0}^{c} \alpha^k / k!} \)
  - 24 Erls to link with capacity 24 --> 14.6% loss
  - 240 Erls to link with capacity 240 --> 4.9% loss
Demand in Transport Network

- demand to transport network is less dynamic
  - well specified start-end time
  - measured in modular data rates

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Bit Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0 (voice)</td>
<td>0.064</td>
</tr>
<tr>
<td>T1</td>
<td>1.54</td>
</tr>
<tr>
<td>T3</td>
<td>45</td>
</tr>
<tr>
<td>OC-3</td>
<td>155.52</td>
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<tr>
<td>OC-48</td>
<td>2,488.32</td>
</tr>
<tr>
<td>OC-192</td>
<td>9,953.28</td>
</tr>
</tbody>
</table>
A Simple Design Example

- set up links to carry demand under link utilization constraint of 60%.

Demand matrix:

three T1 links, utili. = 19.5%

two T1 links, utili. = 39%
Logical vs. Physical Network View

- traffic networks runs on top of transport network
- two independent logical links might go through same physical link
- implications on failure recovery, restoration, network reliability
- multiple-layer network design
# Network Management Timescale

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Micro-secs</th>
<th>Mili-secs</th>
<th>Seconds</th>
<th>Minutes</th>
<th>Hours</th>
<th>Days</th>
<th>Weeks</th>
<th>Months</th>
</tr>
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</table>
**Network Management Cycle**

**Traffic Network (IP, circuit-switched)**

- Capacity change
- Traffic data
- Routing update
- Various controls

**Real-Time Traffic Management**

- Capacity Management, Traffic Engineering
- Network Planning

**Network Planning**

- Months-years
- Days-weeks
- Secs-mins

**Forecast adjustment, Marketing input**

**Transport Network**

- New Transport Demand, Marketing input
- Network fill factor, loading
- Route loading
- Restoration
- Capacity expansion/protection

**Near Real-Time Management**

- Capacity Management, Network Engineering
- Network Planning

**Network Management**

- Months-years
- Days-weeks
- Mins-hours
Course Scope

- Network View
  - different routing, flow and link capacity representations
  - uncertainties: link/node failures, traffic variations
  - multi-layer interaction: traffic/transport, logical/physical
  - large scale problems

- Approaches/algorithms/theory view
  - model selection
  - solution with optimization tools
  - approximate/heuristic algorithms for large problems
  - fundamental principles

- Small timescale management not covered here
  - stochastic queueing analysis and simulation topics for EL735
List of Topics

- Network Design Problem Modeling
- Optimization Methods
- Multi-Commodity Flow Routing
- Location and Topological Design
- Fair Network
- Resilient Network Design
- Robust Network Design
- Multi-Layer Networks