Lecture 2:
Network Design and Topology

CS 598: Advanced Internetworking
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Administrivia
Today’s lecture: Internet topology

• How should I design my network’s topology?

• What is the network topology of the Internet?
  – How can we measure the Internet topology?

• Can we model the Internet’s topology, e.g., for simulation purposes?
  – Interconnection patterns, traffic distribution
Today’s lecture: Internet topology

• Preliminaries
  – Network elements: router/link design

• Designing the topology
  – Hub-and-spoke, backbones, provider/peering

• Modeling the topology
  – Graph-based characterizations

• Measuring the topology
  – Traceroute probes, locating IP addresses
Topology Design
Problem Statement

Sender / Source

Build Network
(1) Low latency
(2) Low cost

Many Receivers
What is a node?

**Links**
- Fibers
- Coaxial Cable

**Interfaces**
- Ethernet card
- Wireless card

**Switches/routers**
- Large router
- Telephone switch
Given a graph $G=(V,E)$
Each edge has $c(e)$ and $l(e)$
Each vertex has demand $d(v)$
Compute graph such that
  - Minimize total $c(e)$ of $e \in E$
  - Minimize $l(e)$ along $(src,dst)$ paths
One approach: Optimization algorithms

- Find value $x$ such that $f(x)$ is as large as possible
  - Linear/nonlinear convex/nonconvex optimization
  - Facility location problem

- Marathe et al, 1998
  - Bicriteria optimization of total $c(e)$, $\max l(e)$
  - Factors ($\log n$, $\log n$) where $n = |D|$  

- Meyerson et al, 2000
  - Optimizes sum of $c(e) + d(v)l(v \rightarrow s)$
  - Factor $\log n$ where $n = |D|$  

- Various other results assuming $c(e)$ and $l(e)$ are somehow related
Fully connected topology

- All nodes connected to each other
- Doesn’t need switching or broadcasting
- However, number of connections grows quadratically with number of nodes
Bus topology

- All nodes connected to a single, shared cable
- Modern Ethernets are “logical” buses (hubs help propagate signal)
- Simple to manage, cost effective, easy to identify faults, reduced weight
- However, poor fault tolerance, performance low with heavy traffic, termination required
Ring and Daisy-chain topology

- Outperforms bus networks, simple to manage
- Ring networks can reduce number of transmitters by half, but can double travel time
- Can pass around “token” to take turns transmitting
Tree topology

- Can exploit statistical aggregation
- Layout may follow physical/administrative constraints
- But, can be bottleneck at root
- Solution: “FAT Tree”
  - Increase bandwidth on links near the root
Hub-and-spoke topology

- Single hub node
- Common in enterprise networks
- Main location and satellite sites
- However, single point of failure, bandwidth limitations, high delay between sites, costs to backhaul and hub
- How can we improve upon hub and spoke?
Improvements to hub-and-spoke

- Dual hub-and-spoke
  - Higher reliability
  - Higher cost
  - Good building block

- Levels of hierarchy
  - Reduce backhaul cost
  - Aggregate the bandwidth
  - Shorter site-to-site delay
• Backbone networks
  – Multiple Points-of-Presence (PoPs)
    • Each with (easily) 40 routers
  – Lots of communication between PoPs
  – Need to accommodate diverse traffic demands
  – Need to limit propagation delay
Abilene Internet2 Backbone
Points-of-Presence (PoPs)

• **Inter-PoP links**
  – Long distances
  – High bandwidth

• **Intra-PoP links**
  – Short cables between racks or floors
  – Aggregated bandwidth

• **Links to other networks**
  – Wide range of media and bandwidth
Deciding Where to Locate Nodes and Links

• Placing Points-of-Presence (PoPs)
  – Large population of potential customers
  – Other providers or exchange points
  – Cost and availability of real-estate
  – Mostly in major metropolitan areas

• Placing links between PoPs
  – Already fiber in the ground
  – Needed to limit propagation delay
  – Needed to handle the traffic load
Customer Connecting to a Provider

Provider

1 access link

Provider

2 access routers

Provider

2 access links

Provider

2 access PoPs
Multi-Homing: Two or More Providers

- Motivations for multi-homing
  - Extra reliability, survive single ISP failure
  - Financial leverage through competition
  - Better performance by selecting better path
  - Gaming the 95th-percentile billing model