From Links to Networks

So far, we’ve learned about tools to help us communicate point-to-point. I.e., a link.

Your Network Here!

Bits and frames
Waveforms
How to Build a Network

- Idea: Compose many point-to-point links
  - Simplest approach: link between each pair of nodes
  - Why not?
    - Too expensive! How does #links scale?

Technology Trends

- Technology trends are important in computer systems design
- Rate of change of technology is an important issue
Solution: Sharing

- Fundamental to how networks are designed
- A switch is a special computer that allows many concurrent communications to share the network
Muscle-Powered Communications

- Human messengers on foot or horseback
  - “Command and Control” between capital and the field
  - 14 AD: Roman relays—50 miles per day for regular mail, 100 miles per day for express mail
  - 1280 AD: Kublai Khan—200-250 mi per day
    - “Poste Haste”— “Fast Post” —riders signal by horns
“Let us turn now to the system of post-horses by which the Great Khan sends his dispatches. You must know that the city of Khan-balik is a centre from which many roads radiate to many provinces, one to each, and every road bears the name of the province to which it runs. … When one of the Great Khan’s messengers sets out along any of these roads, he has only to go twenty-five miles and there he finds a posting station, which in their language is called yamb and in our language may be rendered as ‘horse post’. … Here the messengers find no less that 400 horses, stationed here by the Great Khan’s orders and always kept in readiness for his messengers …”

"By this means the Great Khan’s messengers travel throughout his dominions and have lodgings and horses fully accoutred for every stage. … The whole organization is so stupendous and so costly that it baffles speech and writing.”

-- Marco Polo (1290)

[Extracted from “Empire of the Air: The Men Who Made Radio”, by Tom Lewis]

An early “switched” network: The optical telegraph

- Chappe (1763-1805), a “defense contractor”; 1st message successfully sent in 1794
- 1799: Napoleon seizes power; sends “Paris is quiet, and the good citizens are content.”
- 1814: Extends from Paris to Belgium & Italy
- 1840: 4000 miles, 556 stations, 8 main lines, 11 sublines, each hop ~10 km
- Many “advanced” techniques: framing, codes, redundant relays, message acks, priority messages, error notification, primitive encryption!
And switches today...

- Alcatel 7670 RSP
- Juniper TX8/T640
- TX8
- Avici TSR
- Cisco GSR 12416
- 6ft x 2ft x 1.5ft
- 4.2 kW power
- 160 Gb/s cap.
- Lucent 5ESS telephone switch

Circuit Switching

- It’s the method used by the telephone network
- A call has three phases:
  - Establish circuit from end-to-end (“dialing”),
  - Communicate,
  - Close circuit (“tear down”).
- If circuit not available: “busy signal”
Isochronous Multiplexing/Demultiplexing

One way for sharing a link is TDM:
- A time interval is divided into $n$ frames
- Each frame carries the data of a particular conversation
  - E.g., frame 0 belongs to the red conversation

Circuit Switching
- Suppose link capacity is $C$ bits/sec
- Each communication requires $R$ bits/sec
- $\#frames = C/R$
- Maximum number of concurrent communications is $C/R$

- What happens if we have more than $C/R$ communications?
- What happens if the a communication sends less/more than $R$ bits/sec?

→ Design is unsuitable when traffic arrives in bursts
Data traffic is bursty and rates are variable

5-min average rate on link connecting MIT dorm to building 62 router
Green: incoming traffic; Blue: Outgoing traffic

5-minute traffic averages:
Traffic is bursty and rates are variable
Packet Switching

- Data is sent in **packets** (header contains control info, e.g., source and destination addresses)
- Per-packet forwarding
  - At each node the entire packet is received, buffered, and forwarded
- No capacity is pre-allocated for a particular communicating pair

Queues Absorb Bursts

- **Multiplex** using a queue
  - Switch uses memory to buffer packets
- **Demultiplex** using information in packet header
  - Header has destination (“datagram header”)
  - Switch has a forwarding table that contains information about which link to use to reach a destination
  - Switches build forwarding tables using **routing protocols**
Why Does it Work?
Aggregate Internet Traffic Smooths... (A Little)

5-min average traffic rate at an MIT-CSAIL router

Max In: 12.2 Mb/s  Avg. In: 2.5 Mb/s
Max Out: 12.8 Mb/s  Avg. Out: 3.4 Mb/s

Illustrating statistical multiplexing

Exponential is ideal
Real traffic is Pareto
Plan

• Sharing
  • Switching & channel sharing
  • Lab: ALOHA protocol
    • Understanding throughput, utilization, delay

• Coping with “best effort” properties
  • Layering as a solution
  • Link layer functions

Plan (cont.)

• Network layer: addressing, forwarding, routing
  • Goal: *Universality* (embrace heterogeneity)
  • Lab: Link-state routing, recovering from failure
    • Understand centralized and distributed algorithms

• Transport layer: reliability and windowing
  • Lab: Simple reliable transport protocol

• Scalability
  • Naming, hierarchy, information hiding
  • Simplicity wins
Main Themes

• Sharing

• Reliability

• Scalability