A Taxonomy of Communication Networks

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http://zoo.cs.yale.edu/classes/cs433/

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Outline

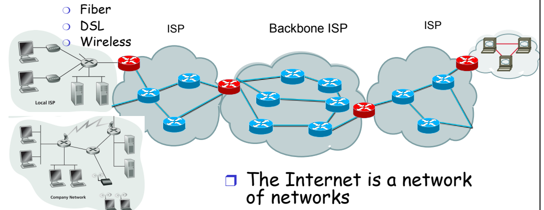
- *Recap*
- A taxonomy of communication networks
- M/M queues and statistical multiplexing

Recap

- A protocol defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission or receipt of a message or other events.
- Some implications of the past:
  - ARPANET is sponsored by ARPA →
    design should survive failures
  - The initial IMPs (routers) were made by a small company → keep the network simple
  - Many networks →
    internetworking: need a network to connect networks
  - Commercialization →
    architecture supporting decentralized, autonomous systems

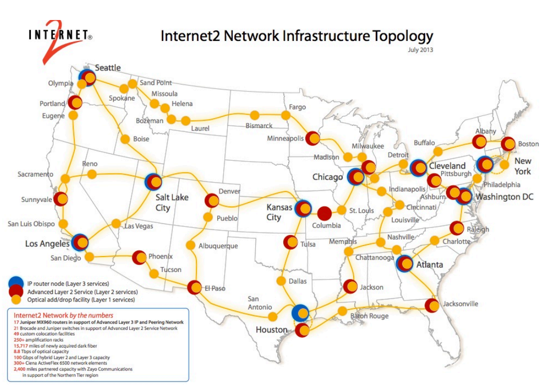
Recap: Internet Physical Infrastructure

Residential access
- Cable
- Fiber
- DSL
- Wireless

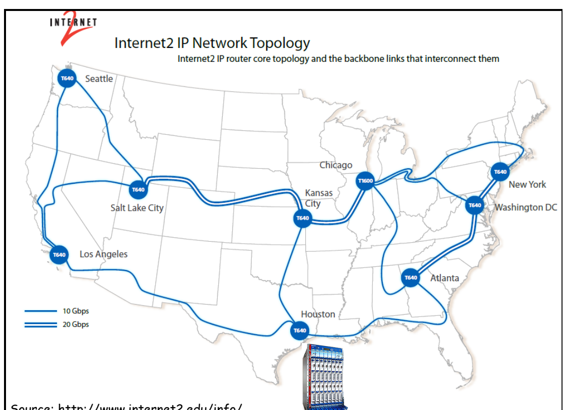


Campus access, e.g.,
- Ethernet
- Wireless

- The Internet is a network of networks
- Each individually administrated network is called an Autonomous System (AS)



Source: http://www.internet2.edu/info/

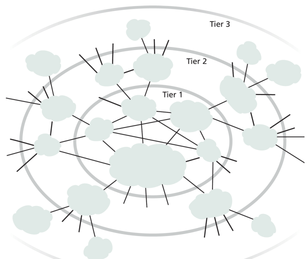


Source: http://www.internet2.edu/info/

Recap: Internet ISP Connectivity

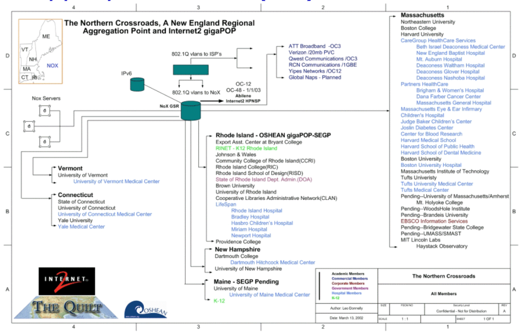
- Roughly hierarchical
  - Divided into tiers
  - Tier-1 ISPs are also called backbone providers, e.g., AT&T, Verizon, Sprint, Level 3, Qwest

  but getting flatter lately.
- An ISP runs (private) Points of Presence (PoP) where its customers and other ISPs connect to it
- ISPs also connect at (public) Internet Exchange Point (IXP)
  - public peering

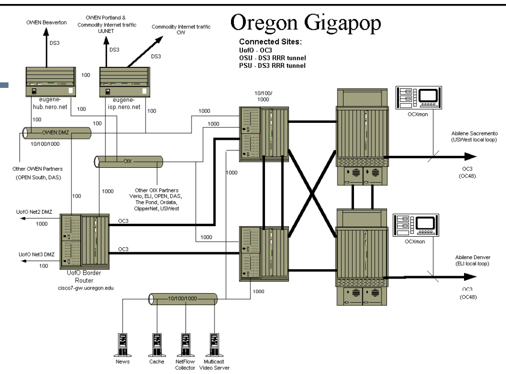


http://en.wikipedia.org/wiki/List_of_Internet_exchange_points_by_size

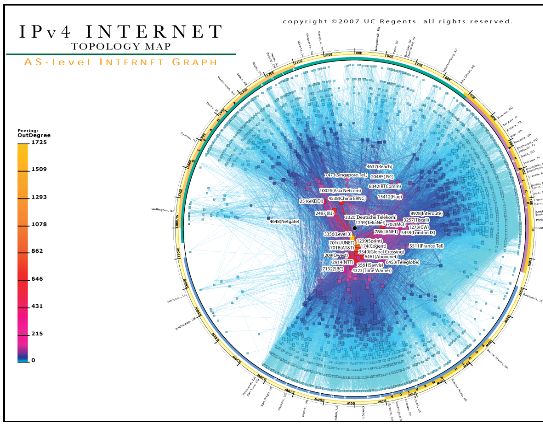
Northern CrossRoads (NoX) Aggregation Point (AP)



http://www.uis.harvard.edu/emerging_technologies/Northern_Crossroads_Map.gif



http://www.oregon-gigapop.net/images/OregonGigapop2.gif



Summary: Internet State

- Global Internet
  - ~ 1 billion hosts
  - 45,033 networks (called ASes)
- Routing overhead/convergence
  - AS updates
    - 2 per second on average
    - 7000 per second peak rate
  - Convergence after a single event can take up to tens of minutes

http://bgp.potaroo.net/as2.0/bgp-active.html

Observing the Internet State

- Read the manual of traceroute, and try it on a zoo machine

  % /usr/sbin/traceroute <machine_name>

- Look at the web sites of the routers you see through traceroute

- Try fixedorbit to look for info (e.g., neighbors) about a network:
  http://www.fixedorbit.com/search.htm
  https://www.ultratools.com/tools/asnInfo

Recap: Challenges of Internet/Inet Apps

- Scale
- Increasingly stringent QoE
- Security

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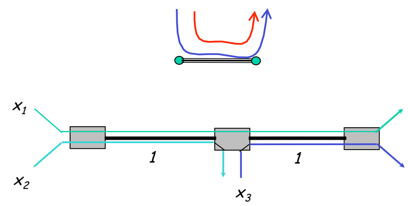
Politics: Sharing a Shared Infrastructure

- question: how to allocate network resources among users?



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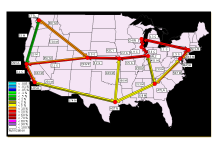
Decentralization: App and Network Interaction

- Network Providers change routing to shift traffic away from highly utilized links
- Adaptive/decentralized apps direct traffic to lower latency paths



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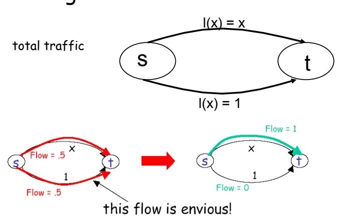
Autonomous ("Selfish") App

- Assume each link has a latency function $l_e(x)$: latency of link e when x amount of traffic goes through e:



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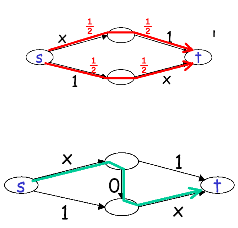
Autonomous ("Selfish") App: Braess' Paradox



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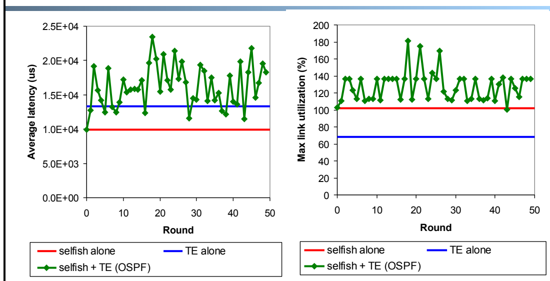
App and Network Interaction



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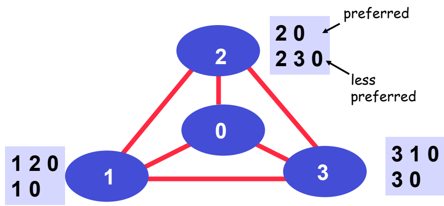
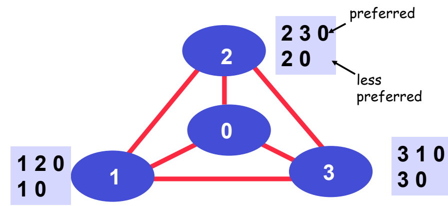
Decentralized ("Selfish") Nets

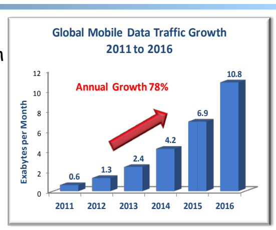


Decentralized ("Selfish") Nets



Fast Wireless Data Growth

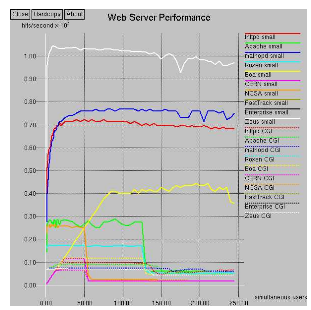
- AT&T
  - Wireless data growth 20,000% in the past 5 years



Problems: Bandwidth limitations and poor TCP performance.

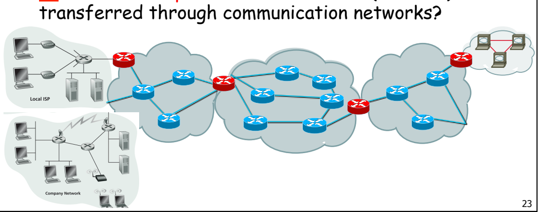
Source: CISCO Visual Networking Index (VNI) Global Mobil Data Traffic Forecast 2011 to 2016

Flexibility vs Performance



Roadmap

- So far we have looked at only the topology and physical connectivity of the Internet: a mesh of computers interconnected via various physical media
- A fundamental question: how are data (the bits) transferred through communication networks?



Outline

- Admin. and recap
- *A taxonomy of communication networks*
- M/M queues and statistical multiplexing

Taxonomy of Communication Networks

communication networks

switched networks | broadcast networks

- Broadcast networks
  - nodes share a common channel; information transmitted by a node is received by all other nodes in the network
  - examples: TV, radio
- Switched networks
  - information is transmitted to a small sub-set (usually only one) of the nodes

A Taxonomy of Switched Networks

communication networks

switched networks | broadcast networks

circuit-switched networks (e.g. telephone) | packet-switched networks (e.g. Internet)

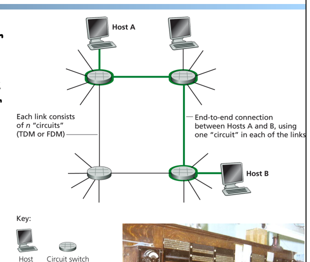
- Circuit switching: dedicated circuit per call/session:
  - e.g., telephone, GSM High-Speed Circuit-Switched Data (HSCSD)
- Packet switching: data sent thru network in discrete "chunks"
  - e.g., Internet, 3G data

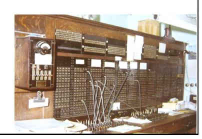
Outline

- Admin. and review
- *A taxonomy of communication networks*
  - *circuit switched networks*
  - packet switched networks
  - circuit switching vs. packet switching

Circuit Switching

- Each link has a number of "circuits"
  - sometime we refer to a "circuit" as a channel or a line
- An end-to-end connection reserves one "circuit" at each link

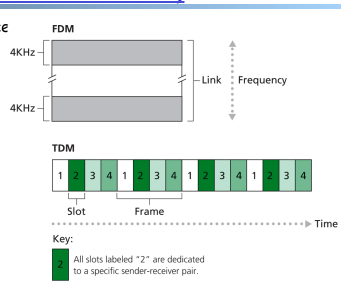




First commercial telephone switchboard was opened in 1878 to serve the 21 telephone customers in New Haven

Circuit Switching: Resources/Circuits (Frequency, Time and others)

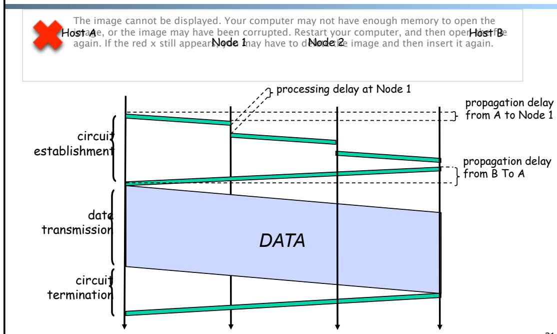
- Divide link resource into "circuits"
  - frequency division multiplexing (FDM)
  - time division multiplexing (TDM)
  - others such as code division multiplexing (CDM), color/ lambda division



Circuit Switching: The Process

- Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination

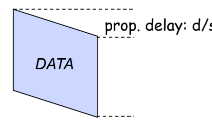
Timing Diagram of Circuit Switching



Delay Calculation in Circuit Switched Networks

- Propagation delay: delay for the first bit to go from a source to a destination

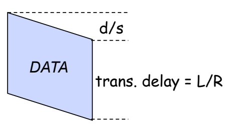
Propagation delay:
- d = length of physical link
- s = propagation speed in medium (~2x10^5 km/sec)



Delay Calculation in Circuit Switched Networks

- Transmission delay: time to pump data onto link at *line* rate

Transmission delay:
- R = reserved bandwidth (bps)
- L = message length (bits)



An Example

- Propagation delay
  - suppose the distance between A and B is 4000 km, then one-way propagation delay is:

$$\frac{4000\,km}{200{,}000\,km/s} = 20ms$$

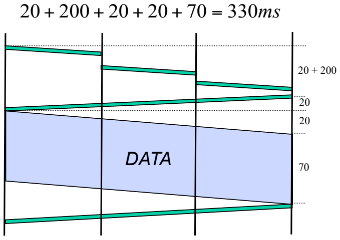
- Transmission delay
  - suppose your iphone reserves a one-slot HSCSD channel
    - each HSCSD frame can transmit about 115 kbps
    - a frame is divided into 8 slots
  - then the transmission delay of using one reserved slot for a message of 1 Kbits:

$$\frac{1kbits}{14kbps} \approx 70ms$$

An Example (cont.)

- Suppose the setup message is very small, and the total setup processing delay is 200 ms
- Then the delay to transfer a message of 1 Kbits from A to B (from the beginning until host receives last bit) is:

$$20 + 200 + 20 + 20 + 70 = 330ms$$



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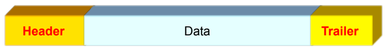
  - circuit switched networks
  - *packet switched networks*

Packet Switching

Each end-to-end data **flow** (i.e., a sender-receiver pair) divided into ***packets***

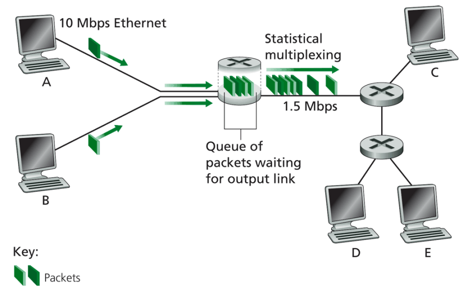
- Packets have the following structure:



  - header and trailer carry control information (e.g., destination address, check sum)
  - where is the control information for circuit switching?

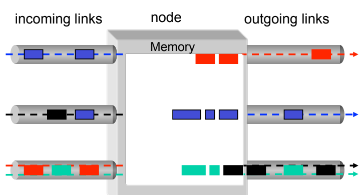
- At each node the entire packet is received, processed (e.g., routing), stored briefly, and then forwarded to the next node; thus packet-switched networks are also called **store-and-forward networks**

Packet Switching



Inside a Packet Switching Router

An output queueing switch



Packet Switching: Resources

- Resources used *as* ***needed***
- On its turn, a packet uses full link bandwidth

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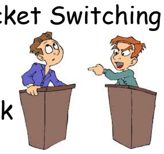
  - *circuit switching vs. packet switching*

Packet Switching vs. Circuit Switching

- The early history of the Internet was a heated debate between Packet Switching and Circuit Switching
  - the telephone network was the dominant network



- Need to compare packet switching with circuit switching

Circuit Switching vs. Packet Switching

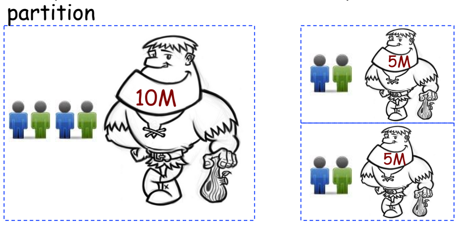
	circuit switching	packet switching
resource usage		
reservation/setup		
resource contention		
charging		
header		
fast path processing		

Circuit Switching vs. Packet Switching

	circuit switching	packet switching
resource usage	use a single partition bandwidth	use whole link bandwidth
reservation/setup	need reservation (setup delay)	no reservation
resource contention	busy signal (session loss)	congestion (long delay and packet losses)
charging	time	packet
header	no per-pkt header	per packet header
fast path processing	fast	per packet processing

Key Issue to be Settled

- A key issue: what is the efficiency of resource partition



- Tool used to analyze the issue: queueing theory
  - Some basic results of queueing can be quite useful

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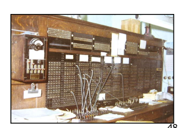
Queueing Theory

- We are not interested in extremely precise modeling, but want quantitative intuition
- Strategy:
  - model system state
    - if we know the fraction of time that the system spends at each state, we can get answers to many basic questions: how long does a new request need to wait before being served?
- System state changes upon events:
  - introduce state transition diagram
  - focus on equilibrium: state trend neither growing nor shrinking

Warm up: Analysis of Circuit-Switching Blocking (Busy) Time

- Assume a link has only a finite number of N circuits
- Objective: compute the percentage of time that a new session (call) is blocked



Analysis of Circuit-Switching Blocking (Busy) Time

- Consider a simple arrival pattern
  - client requests arrive at a rate of λ (lambda/second)
  - service rate: each call takes on average $1/\mu$ second
- Arrival and service patterns: memoryless (Markovian)
  - During a small interval Δt, the number of new arrivals is: $\lambda \Delta t$
  - During a small interval Δt, the chance of a current call finishes is: $\mu \Delta t$
- This model is also called an M/M/N model

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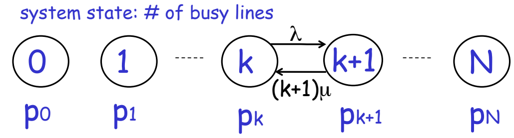
Analysis of Circuit-Switching Blocking (Busy) Time: State

system state: # of busy lines



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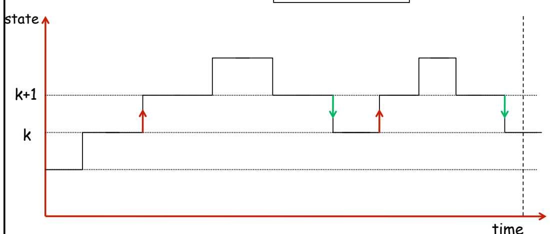
Equilibrium = Time Reversibility

- Statistically cannot distinguish $\boxed{\#f_{k\rightarrow k+1},\quad \#f_{k+1\rightarrow k}}$ $\boxed{\#b_{k\rightarrow k+1},\quad \#b_{k+1\rightarrow k}}$



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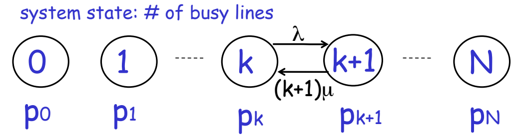
Analysis of Circuit-Switching Blocking (Busy) Time: Sketch

system state: # of busy lines



at equilibrium (time resersibility) in one unit time:

#(transitions k → k+1) = #(transitions k+1 → k)

$$\boxed{p_k \lambda = p_{k+1}(k+1)\mu}$$

$$\boxed{p_{k+1} = \tfrac{1}{k+1}\tfrac{\lambda}{\mu} p_k = \tfrac{1}{(k+1)!}\left(\tfrac{\lambda}{\mu}\right)^{k+1} p_0}$$

$$\boxed{p_0 = \frac{1}{1 + \frac{1}{1!}\frac{\lambda}{\mu} + \frac{1}{2!}\left(\frac{\lambda}{\mu}\right)^2 + \ldots + \frac{1}{N!}\left(\frac{\lambda}{\mu}\right)^N}}$$

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