Introduction

CSC 573 Internet Protocols
Spring 2019

Agenda

1. History
2. Internet Structure
3. Packet vs circuit switching
4. TCP/IP Protocol Stack

History

- Cerf and Kahn are considered the Internet founding fathers
  - Vinton Cerf -> Born in 1943, DARPA program manager, funded and chairman of ICANN, president of ACM
  - Bob Kahn -> Born in 1938, Ph.D. from City University of NY, worked at AT&T, and was a professor at MIT

- Established internetworking principles:
  1. *minimalism, autonomy* - no internal changes required to interconnect networks
  2. *best effort* service model
  3. *stateless routers*

define today's Internet architecture

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1960's: Early Packet-Switching Principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1970: ALOHAnet satellite network in Hawaii

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1970's: Internetworking, proprietary nets

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- Late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

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1980's: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

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1990, 2000's: Commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web
- late 1990's – 2000's:
  - more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million hosts, 100 million+ users
  - backbone links running at Gbps

2005 - present

- ~750 million hosts
- Smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Facebook: soon one billion users
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, email, etc.
- E-commerce, universities, enterprises running their services in "cloud" (eg, Amazon EC2)

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Network devices

- Endhosts (servers and clients)
- Routers, switches, and hubs to connect endhosts

- A network consists of some number of endhosts interconnected through routers/switches/hubs
- The Internet interconnects networks

Types of Networks

- Not all networks are created equal! Why?

1. Edge Networks: Carry own traffic

   Examples: Customer networks such as home networks and NCSU network

2. Core Networks: Carry transit traffic; i.e. traffic for their customers (in addition to own traffic)

   Examples: ISP networks such as Sprint, AT&T, Level3, etc

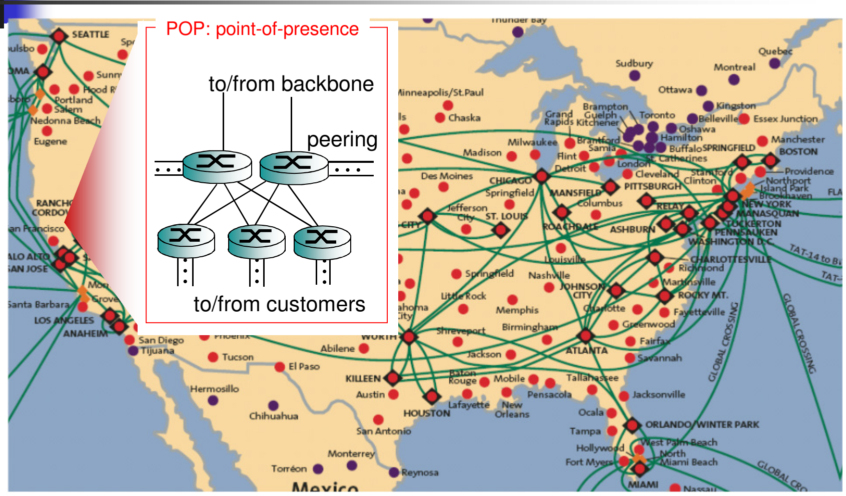
Structure of Edge Networks

- ??
- Why?

Structure of Core Networks

- ??
- Why?

Sprint Network Structure



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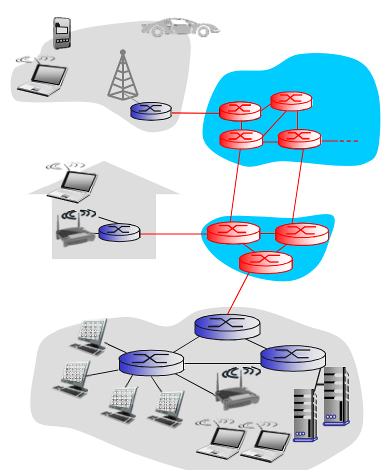
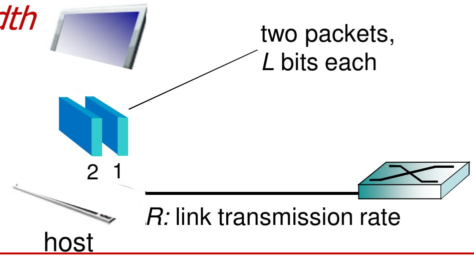
Packet Switching

- Hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
- Packets from different sources *share* intermediate resources



Host sends *packets* of data

- L: Size of each packet in bits
  R: Transmission rate of link in bits/sec
- Link transmission rate, aka link *capacity, aka link bandwidth*



packet transmission delay = time needed to transmit L-bit packet into link = $\frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

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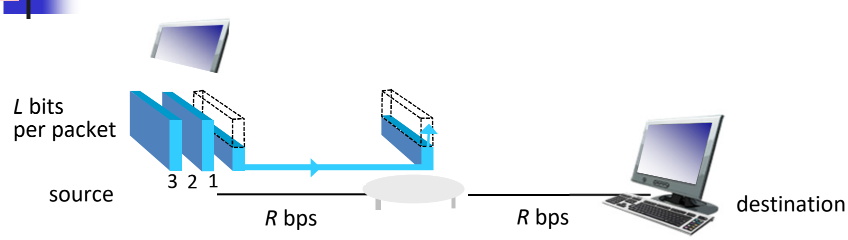
Store-and-forward



- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

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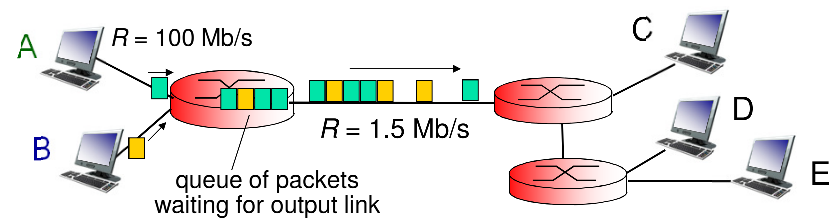
Queueing delay and Packet loss



- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

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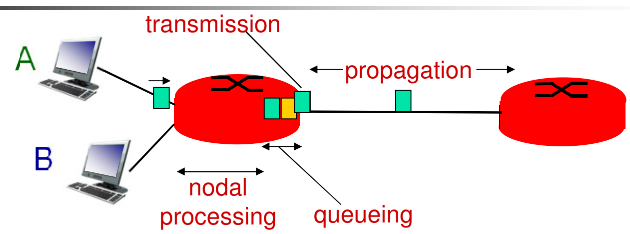
Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on congestion level of router

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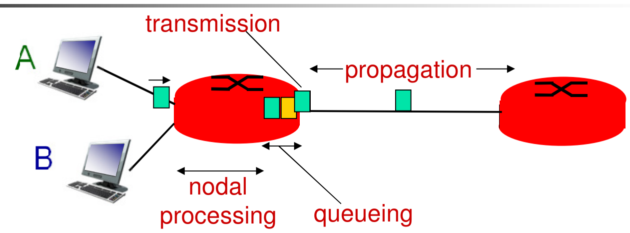
Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed in medium ($\sim 2\text{x}10^8$ m/sec)
- $d_{prop} = d/s$

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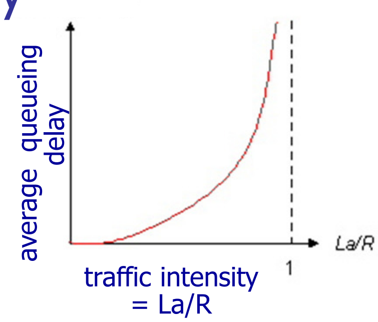
Queueing Delay

- *R:* link bandwidth (bps)
- *L:* packet length (bits)
- a: average packet arrival rate



- *La/R* ~ 0: avg. queueing delay small
- *La/R* ≈ 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

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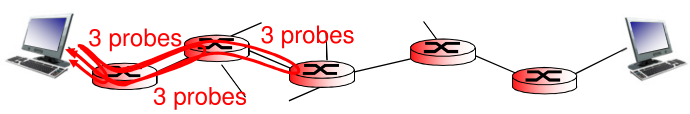
"Real" Internet delays and routes

- `traceroute` program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

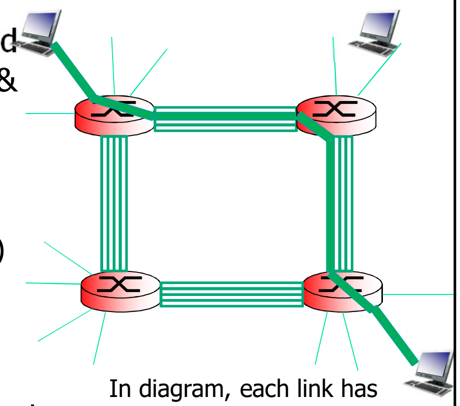
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

Circuit Switching

- end-end resources reserved for "call" between source & dest
- dedicated resources: no sharing
  - circuit-like (*guaranteed*) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks



In diagram, each link has four circuits. call gets 2nd circuit in top link and 1st circuit in right link.

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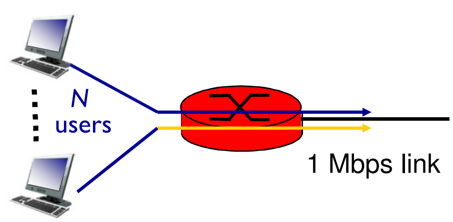
Packet switching vs circuit switching (1/2)



Example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time

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Packet switching vs circuit switching (2/2)

circuit-switching:
10 users
packet switching:
with 35 users, probability > 10 active at same time is less than .0004

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

- *packet switching allows more users to use network!*
- simpler, no call setup
- congestion possible: packet delay and loss

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What's a protocol?

Human protocols:

- "what's the time?"
- "I have a question"

... specific msgs sent

... specific actions taken when msgs received, or other events

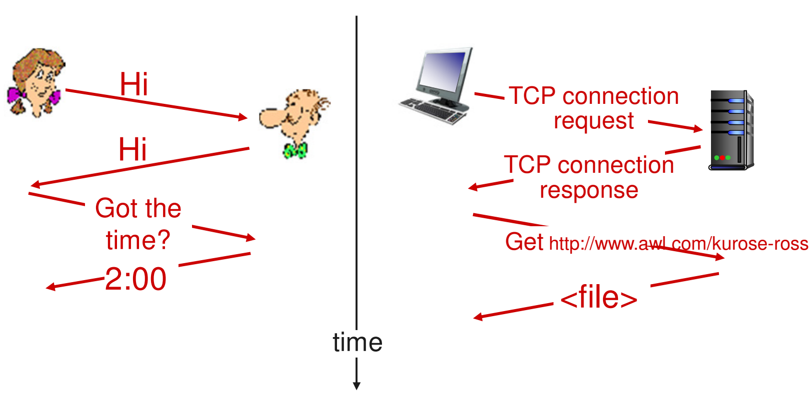
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Protocol "layers"

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of *organizing* structure of network?

.... or at least our discussion of networks?

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Organization of air travel

ticket (purchase)	ticket (complain)
baggage (check)	baggage (claim)
gates (load)	gates (unload)
runway takeoff	runway landing
airplane routing	airplane routing

airplane routing

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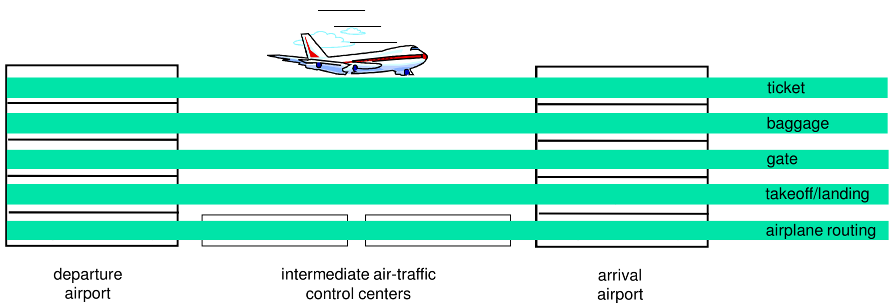
Layering of airline functionality



layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below/above

Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system

Internet protocol stack

- *Application:* supporting network applications
  - FTP, SMTP, HTTP
- *Transport:* process-process data transfer
  - TCP, UDP
- *Network:* routing of datagrams from source to destination
  - IP, routing protocols
- *Link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *Physical:* bits "on the wire"

application
transport
network
link
physical

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ISO/OSI reference model

- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?

application
presentation
session
transport
network
link
physical

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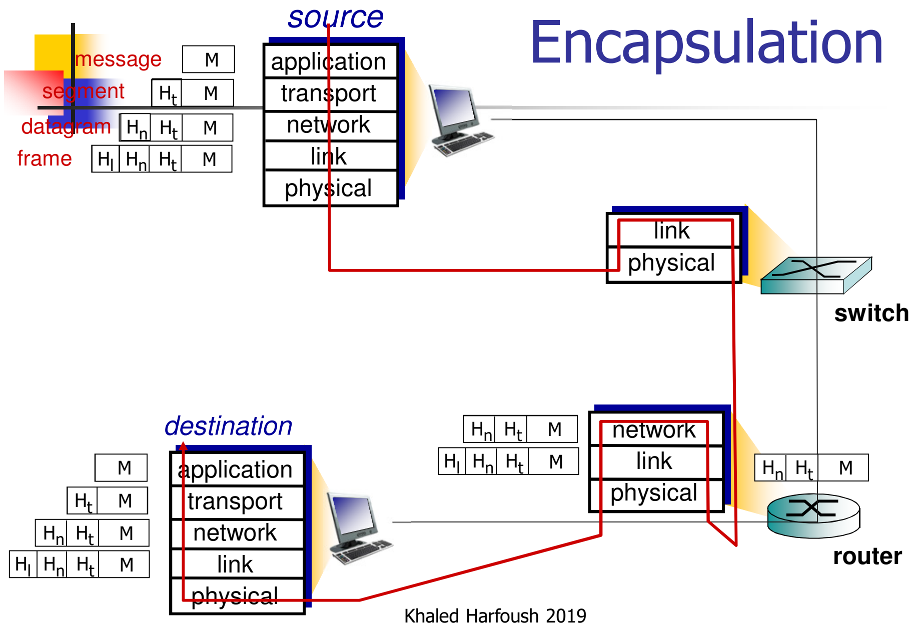
Encapsulation



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Next Lecture

1. Review of PHY and Data Link Layers

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