Computer Networks

Dr. David Koll
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Course Overview

- 29 Oct. 2015 Introduction & Layering
- 05 Nov. 2015 Link Layer I
- 12 Nov. 2015 Link Layer II
- 19 Nov. 2015 Network Layer I
- 26 Nov. 2015 Network Layer II; Routing I
- 03 Dec. 2015 Network Layer III; Routing II; Mobility
- 10 Dec. 2015 Transport Layer I
- 17 Dec. 2015 Transport Layer II
- 07 Jan. 2015 Networked Multimedia
- 14 Jan. 2015 Quality of Service
- 21 Jan. 2015 Network Security I
- 28 Jan. 2015 Network Security II
- 04 Feb. 2015 TBA (probably Q&A session)
- 11 Feb. 2015 Written Examination

Excercises

- Contact e-mail:

  obaraka@gwdg.de

- Homework exercises will be handed out regularly after class and are in the wiki.
- Students are encouraged to work on their own and solve the homework exercises to prepare for the final exam.
- Solutions will be presented one week later after class. Thursdays 12:00 – 13:00 in the lecture room.

Grading

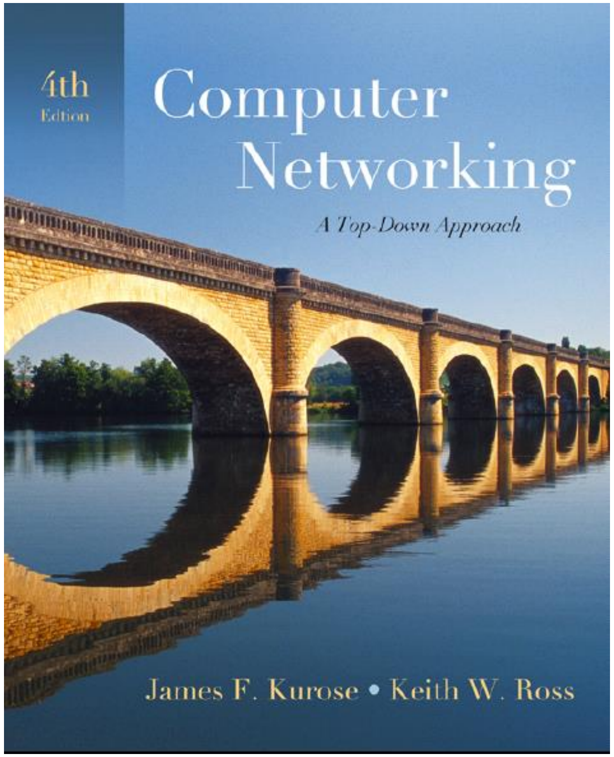
- The grading is as follows:

100% Final exam!

- All important information (click on Computer Networks)

wiki.net.informatik.uni-goettingen.de

Chapter 1
Introduction



This lecture is based on the book:

Computer Networking: A Top Down Approach
4th edition. Jim Kurose, Keith Ross, Addison-Wesley, July 2007.

Alternative textbook:

- A. Tanenbaum, "Computer Networks", 5th edition, Prentice Hall, 2010
- D. Comer, “Computer Networks and Internets”, 5th edition, Prentice Hall, 2008

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

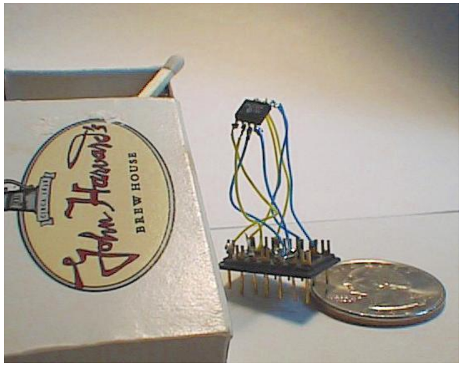
1.5 Protocol layers, service models

1.6 History

“Cool” internet appliances

IP picture frame
http://www.ceiva.com/

Web-enabled toaster + weather forecaster

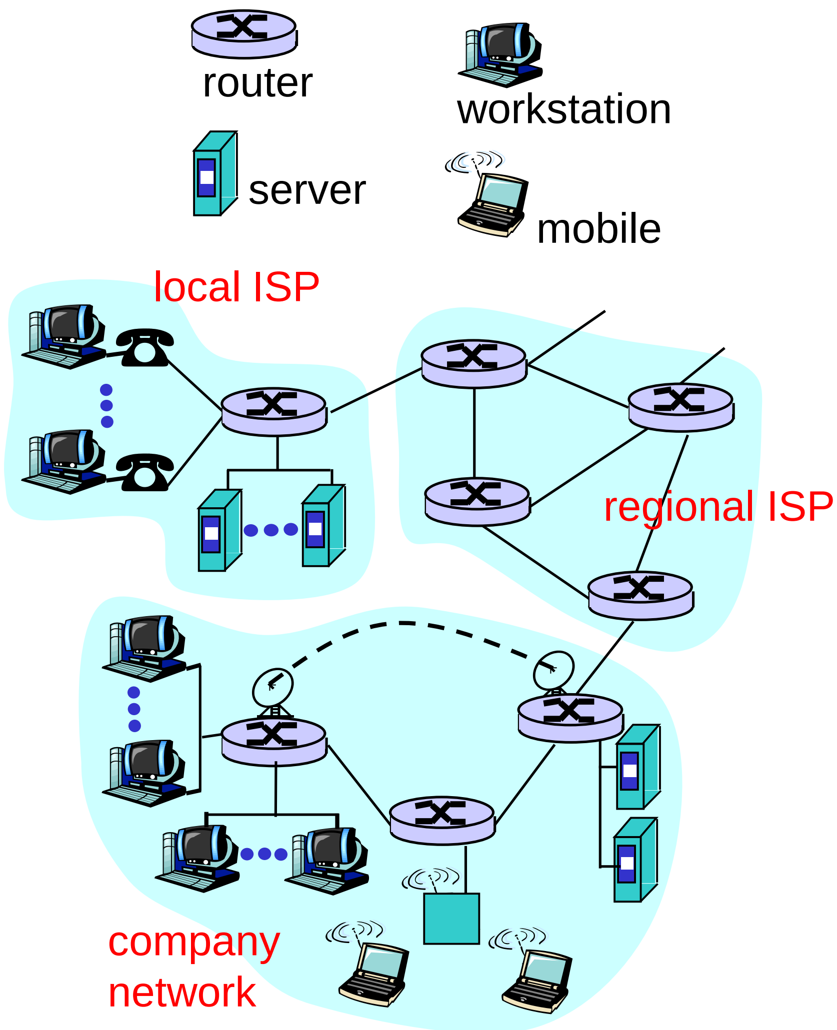


World’s smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Smartphones

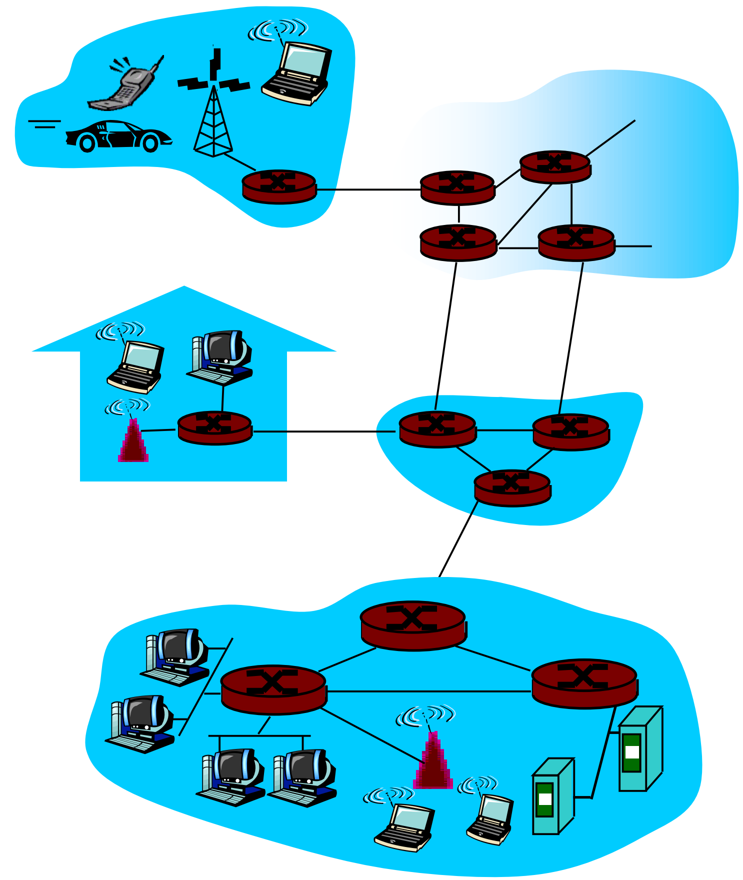
What's the internet? A close look…

- millions of connected computing devices: *hosts, end-systems*
  - PCs, workstations, servers
  - PDAs, phones, toasters
  - running *network apps*
- *communication links*
  - fiber, copper, coax, radio, satellite
  - transmission rate = ***bandwidth***
- *routers:* forward packets (chunks of data)



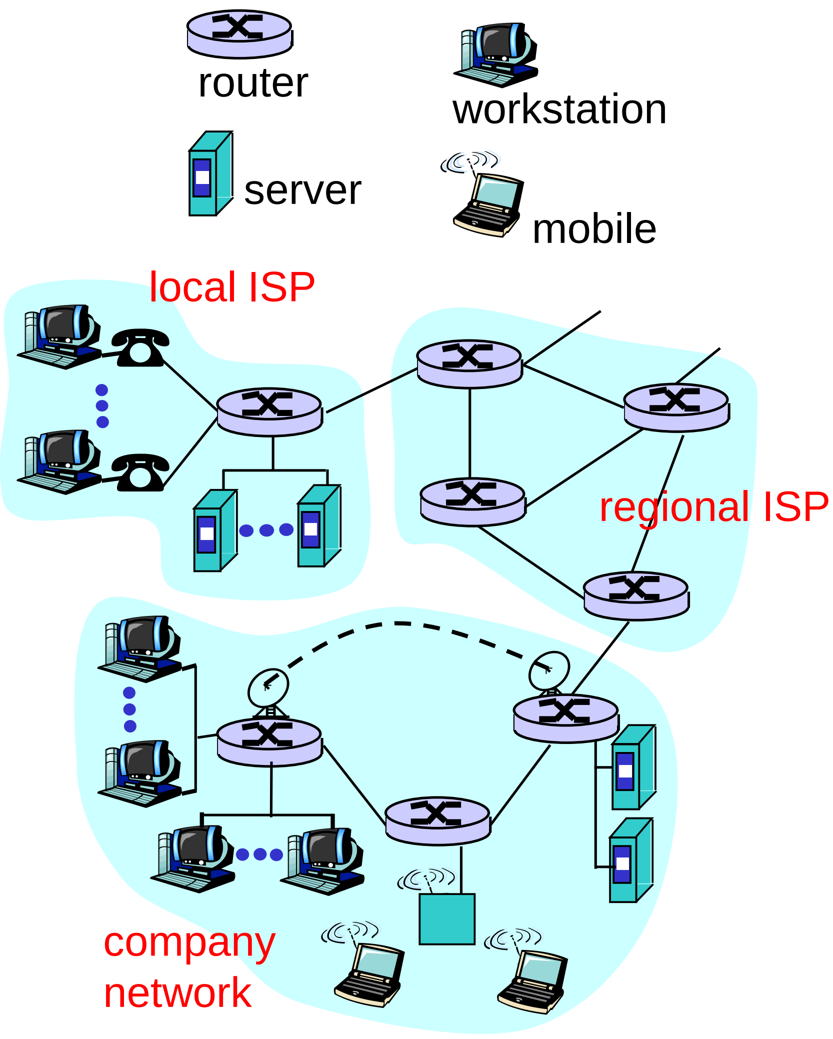
What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing
- communication services provided to apps:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



What's the internet? … and closer

- *protocols* define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



What's a protocol?

human protocols:

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

… specific msgs sent

… specific actions taken when msgs received, or other events

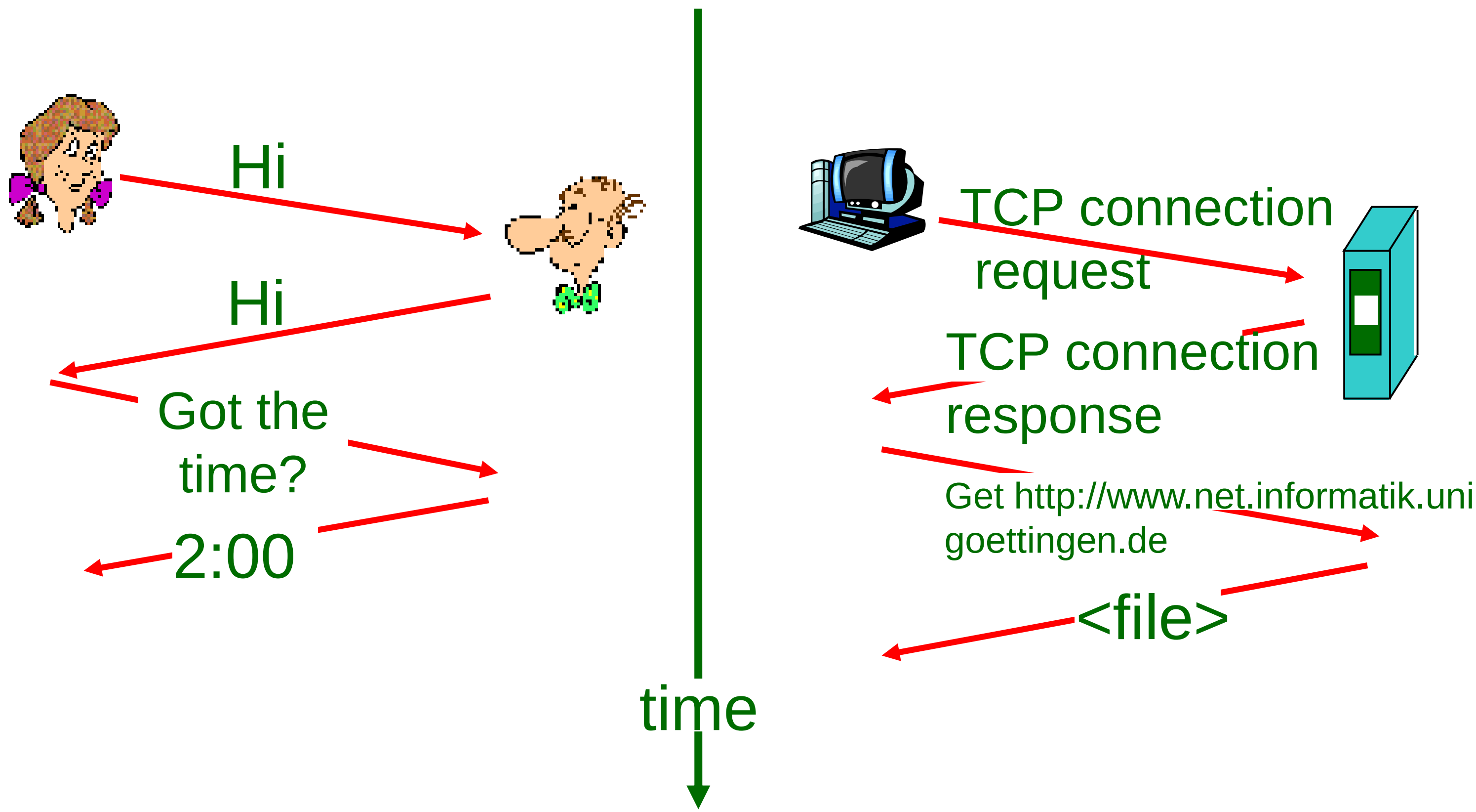
network protocols:

- 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:



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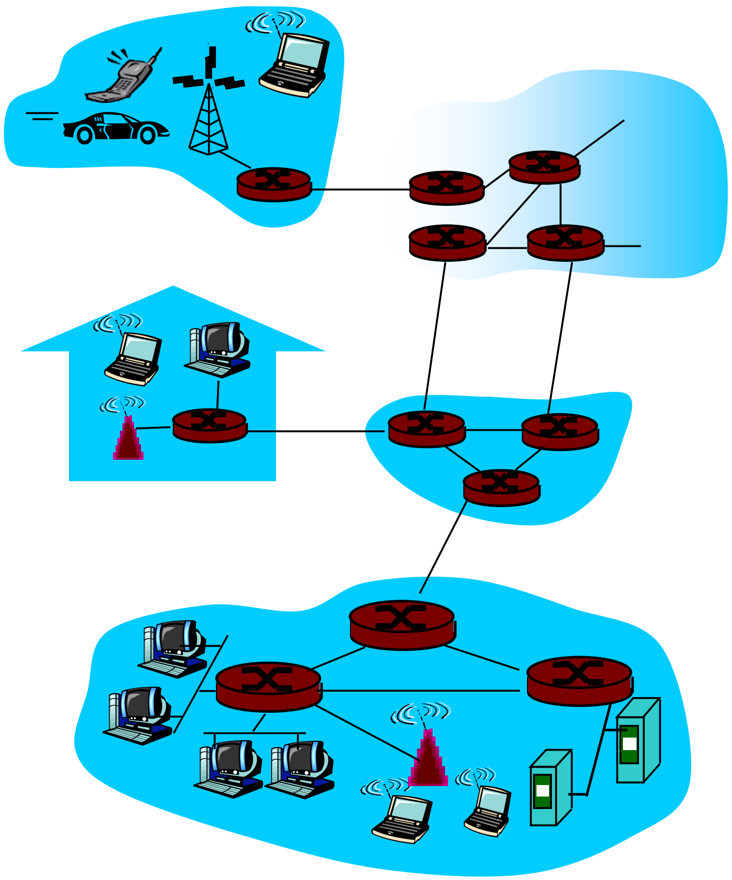
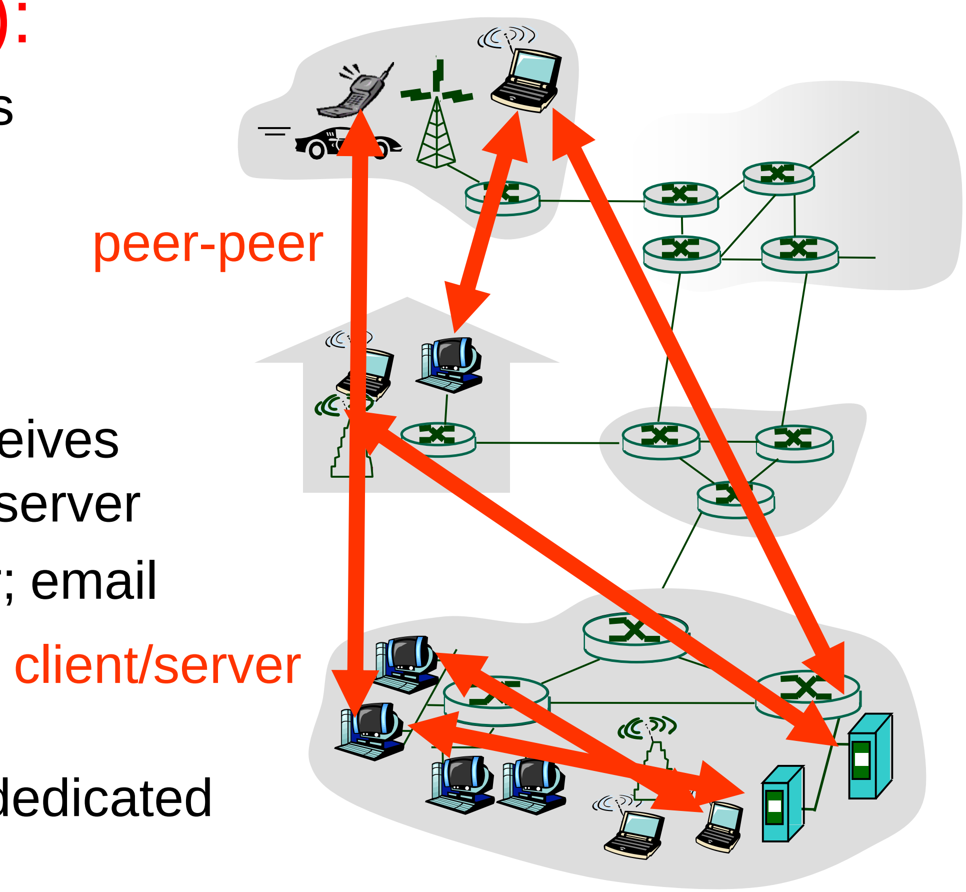
A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



The network edge:

- end systems (hosts):
  - run application programs
  - e.g. web, email
  - at “edge of network”
- client/server model
  - client host requests, receives service from always-on server
  - e.g. web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



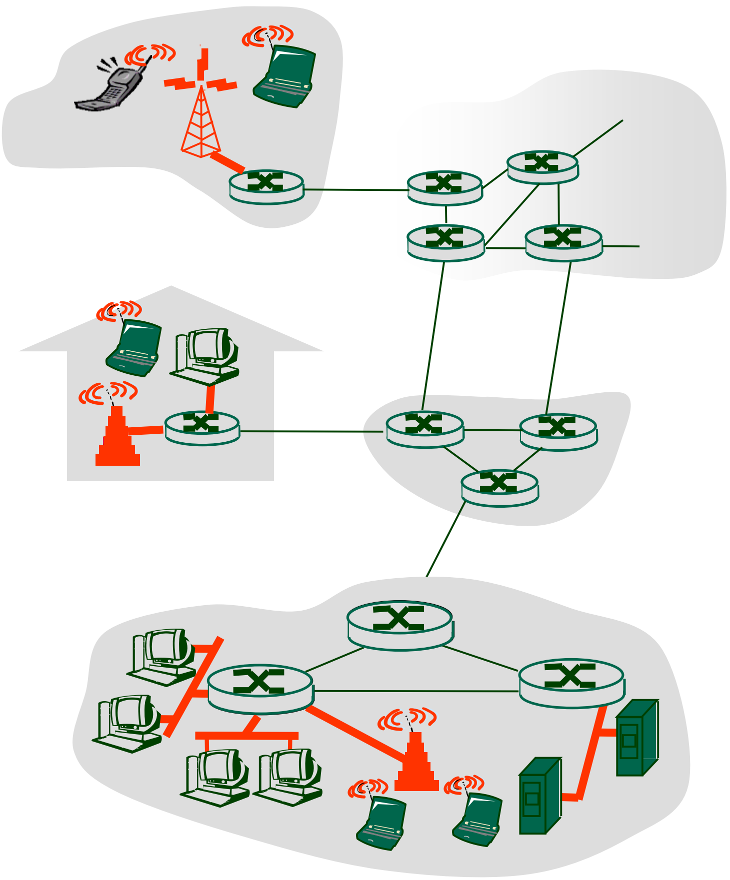
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks

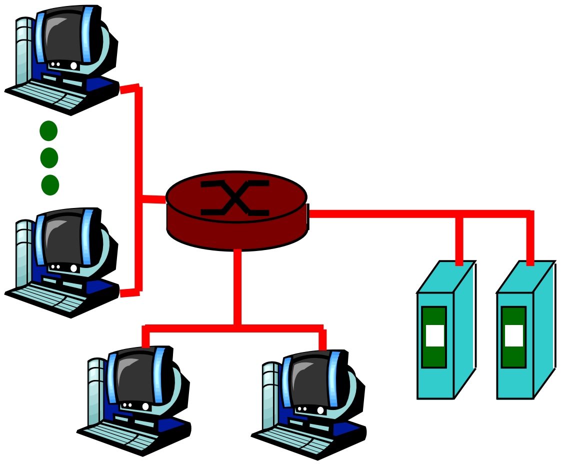
Keep in mind:

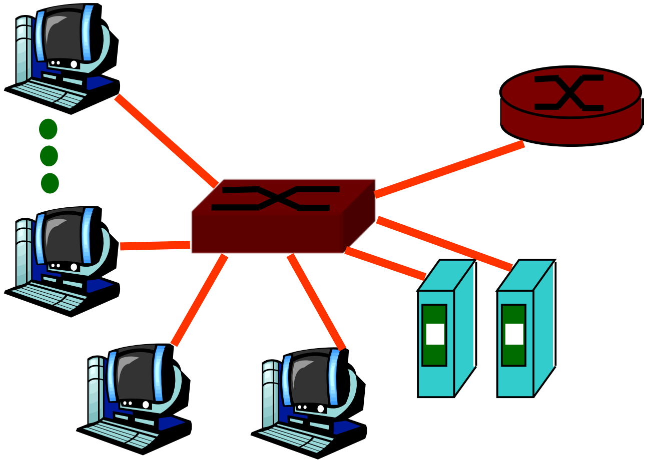
- bandwidth (bits per second) of access network?
- shared or dedicated?



Example: Company access: local area networks

- company/univ local area network (LAN) connects end system to edge router (example: our GöNet)
- Ethernet:
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
  - modern configuration: end systems connect into *Ethernet switch*
- LANs: will be discussed in detail throughout this lecture

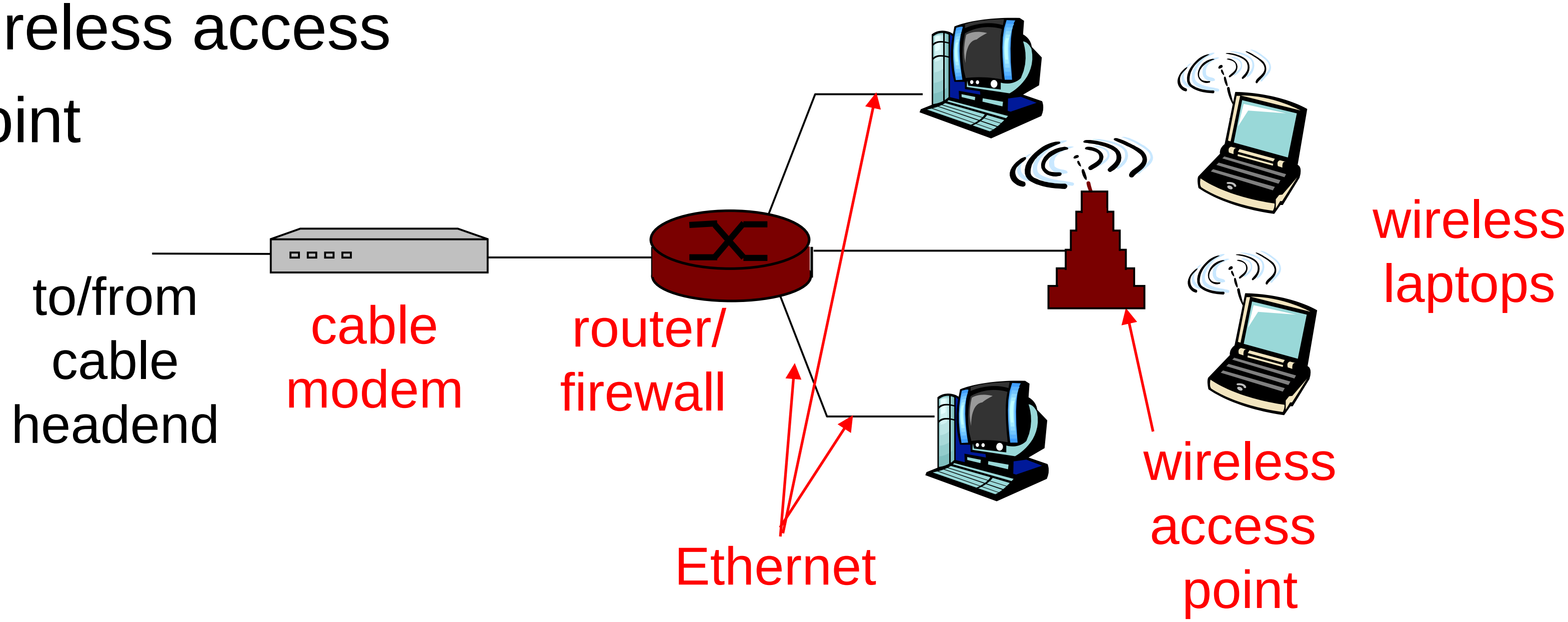




Example: Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point



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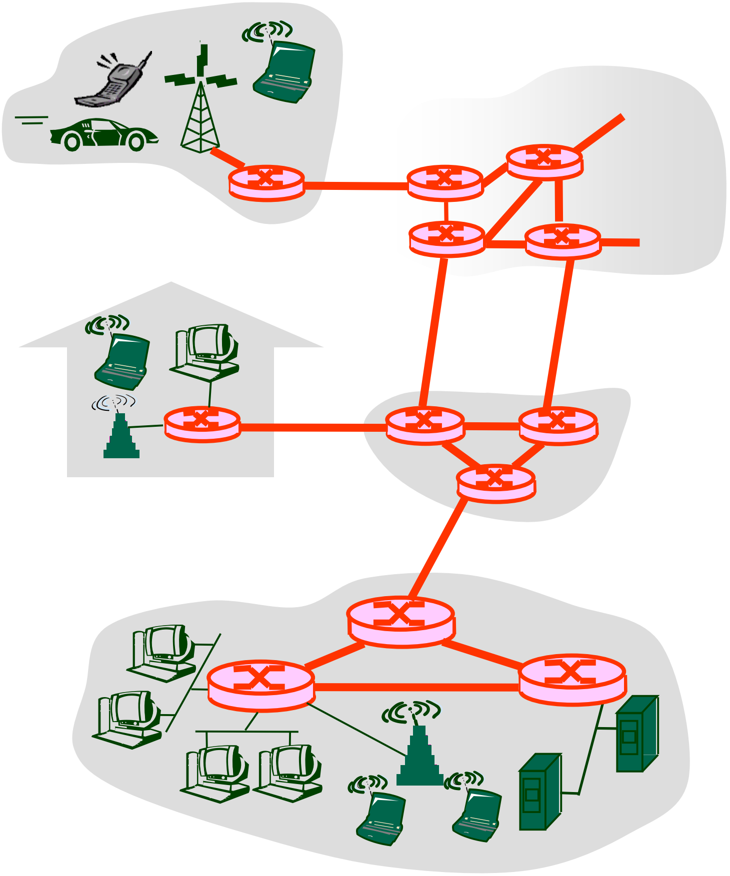
The Network Core

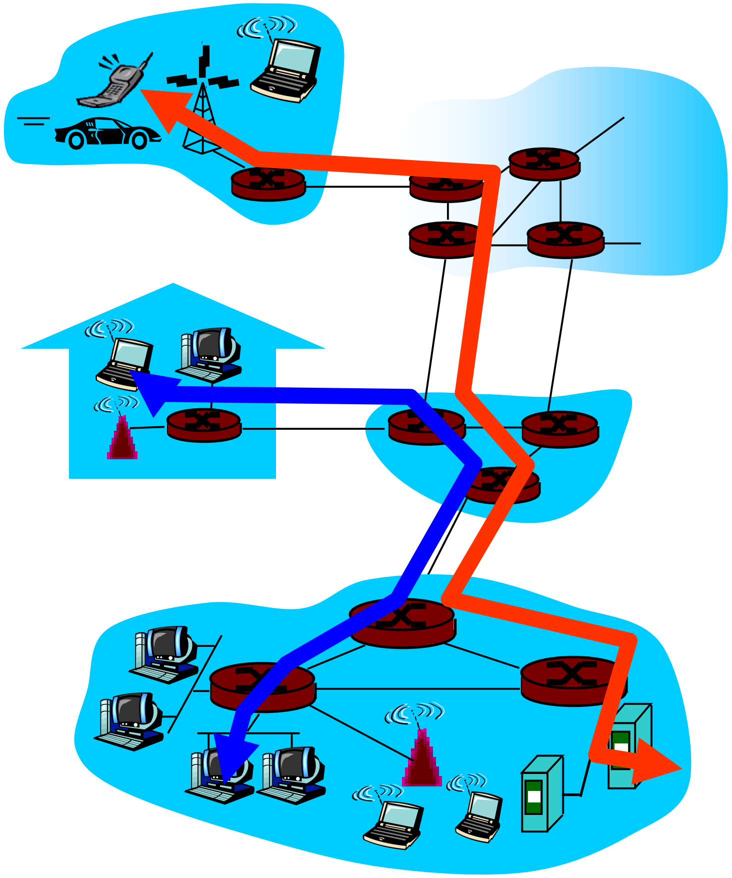
- mesh of interconnected routers
- *<u>the</u>* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone network
  - packet-switching: data sent through a network in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into “pieces”

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

- dividing link bandwidth into “pieces”
  - frequency division
  - time division

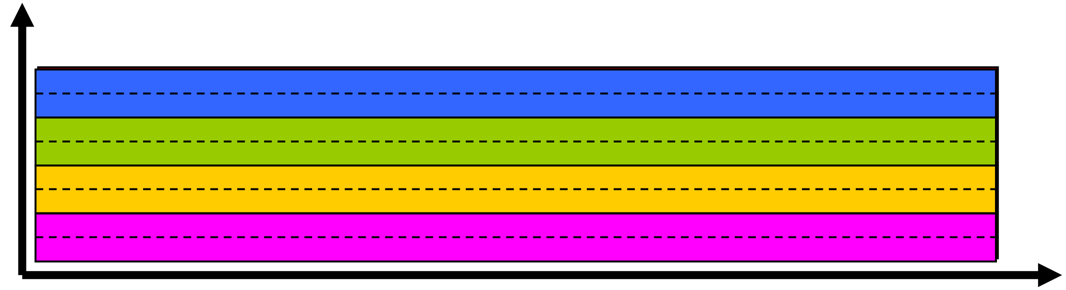
Circuit Switching: FDM and TDM

Example:

4 users

FDM

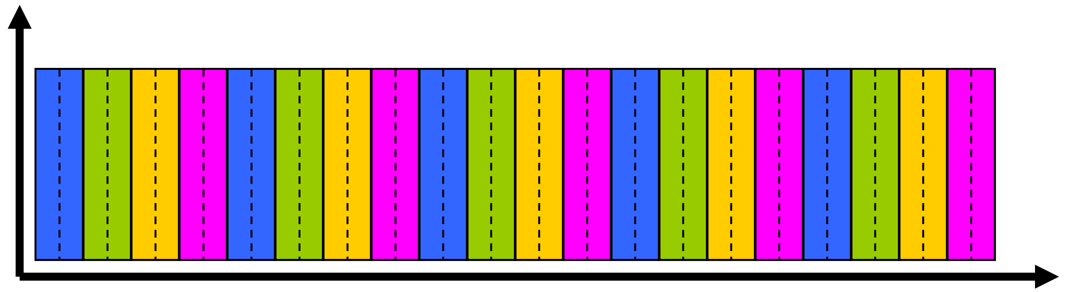
frequency



time

TDM

frequency



time

Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Numerical example

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TDM: A-B bandwidth = link bandwidth / 24 slots = 64Kbps

640,000 bits = 640KB

Hence: 640/64 = 10 sec + 500 msec = 10.5 sec

Network Core: Packet Switching

each end-end data stream divided into *packets*

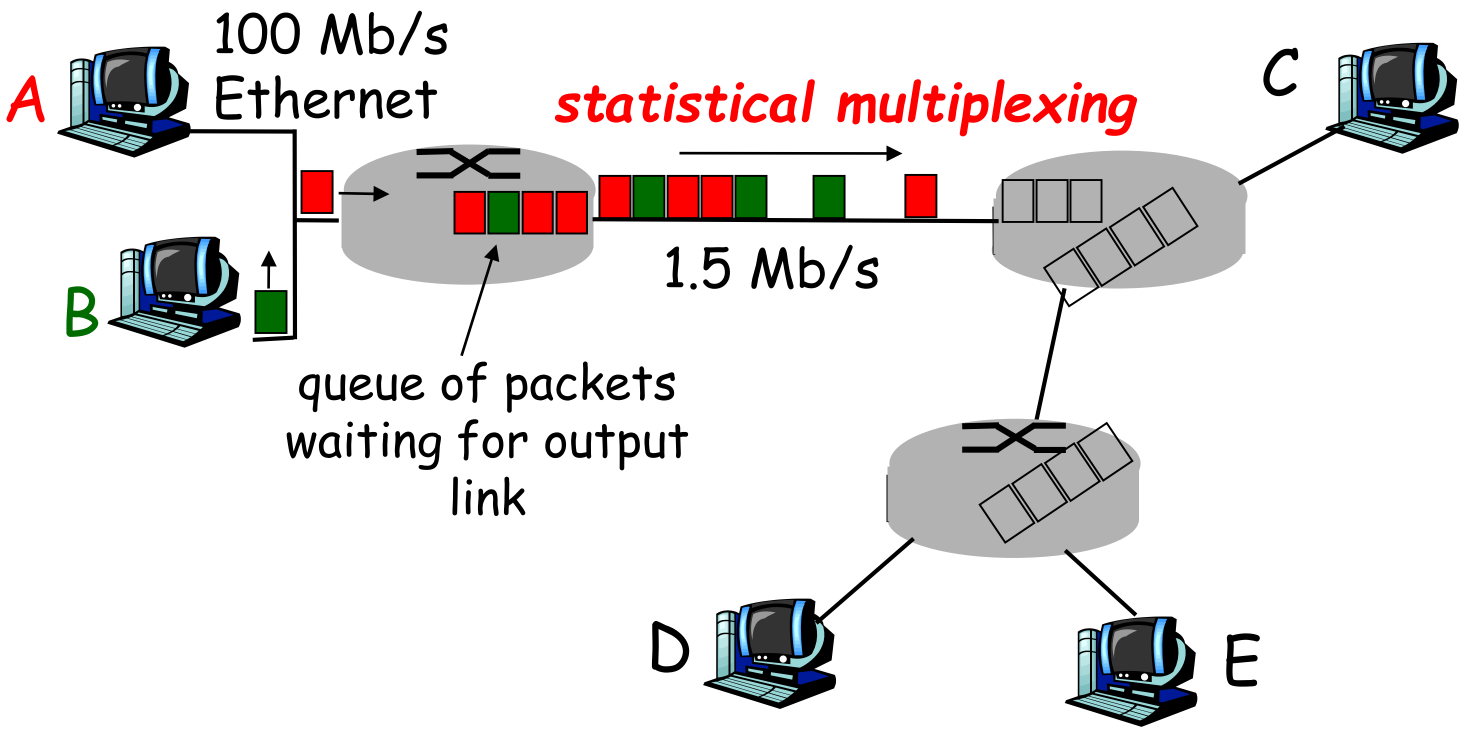
- user A, B packets *share* network resources
  - Sequence of sending packets does not have fixed pattern ➔ ***statistical multiplexing***
- each packet uses full link bandwidth
- resources used *as needed*

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

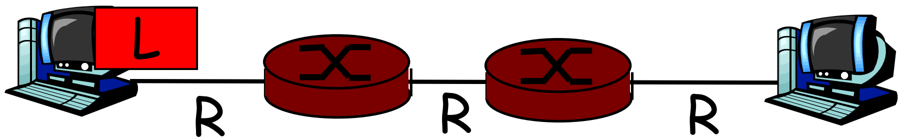
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➔ ***statistical multiplexing***.

TDM: each host gets same slot in revolving TDM frame.

Packet-switching: store-and-forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- store and forward: entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

Note:

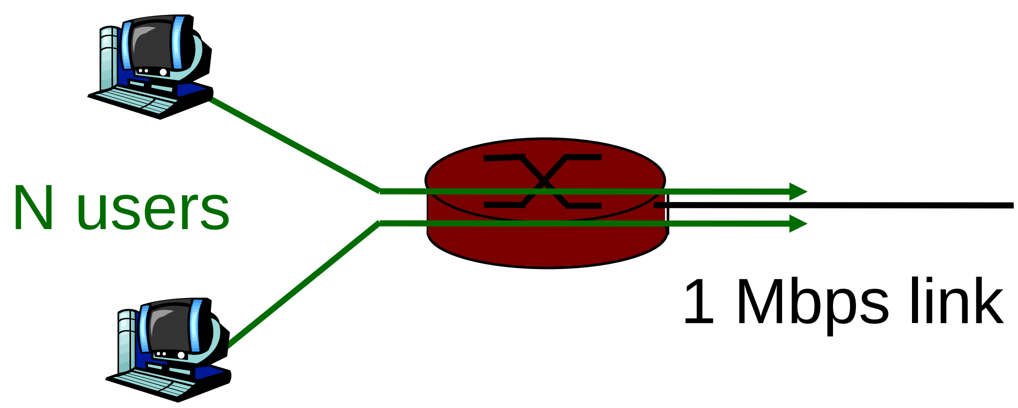
- In order to be more efficient, large packets are usually segmented into smaller packets

➔ *Can you explain why?*

Packet switching versus circuit switching

Packet switching allows more users to use network!

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



- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is low

Packet switching versus circuit switching

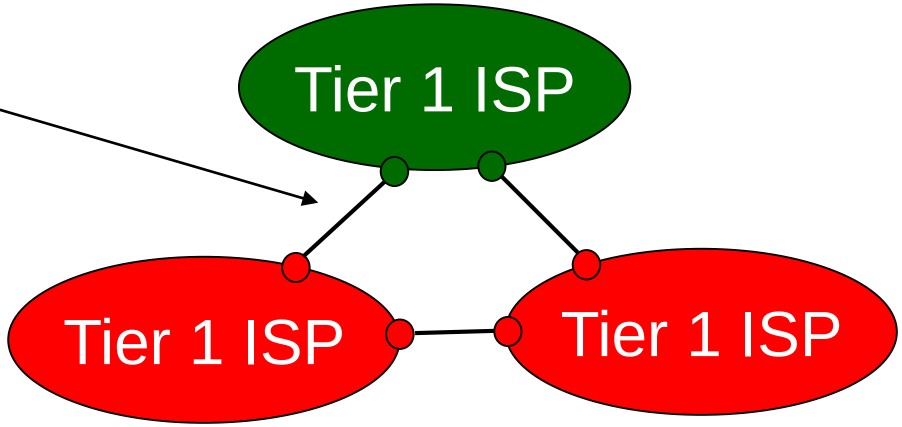
Is packet switching better than circuit switching?

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem

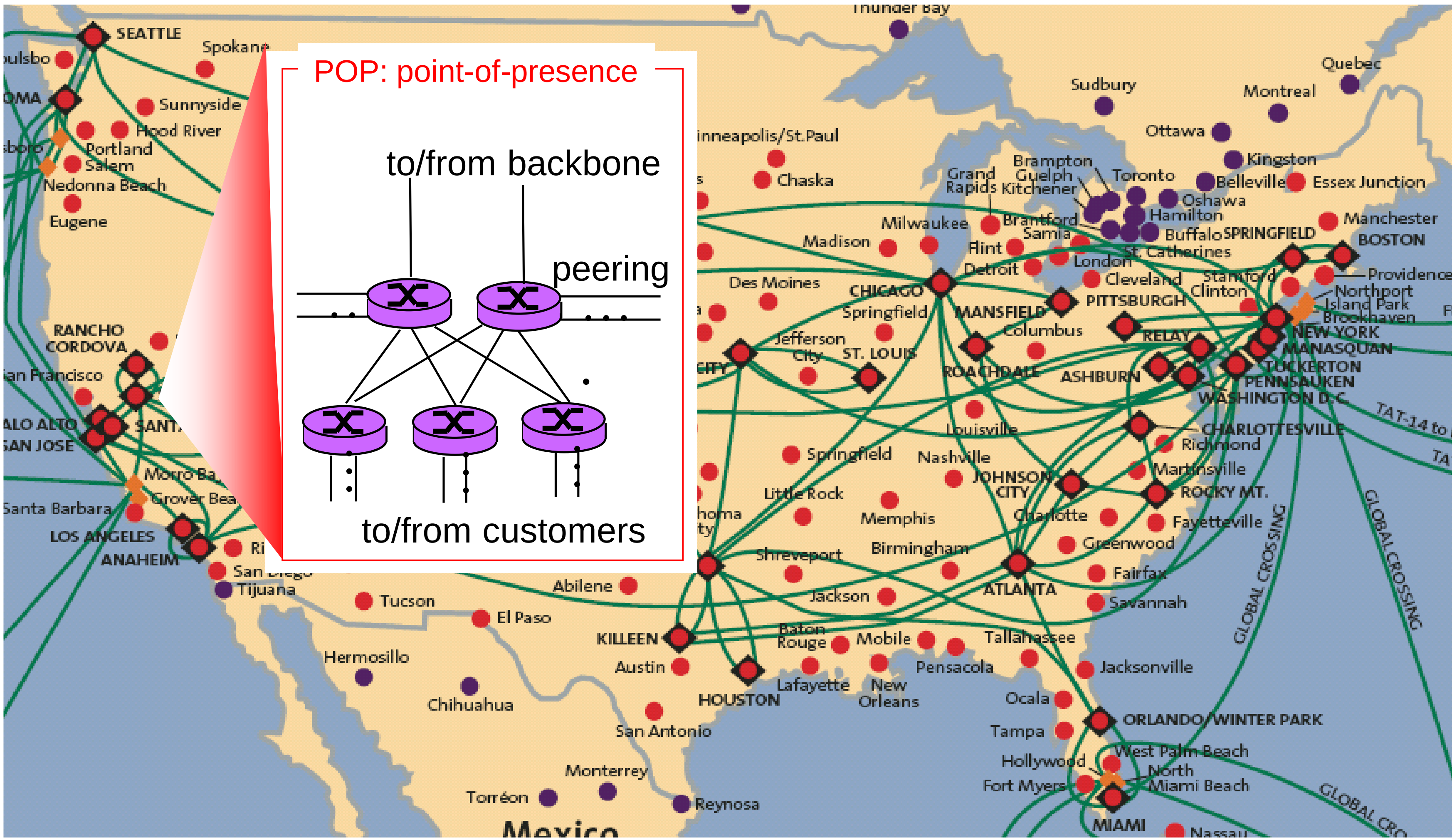
Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals

Tier-1 providers interconnect (peer) privately



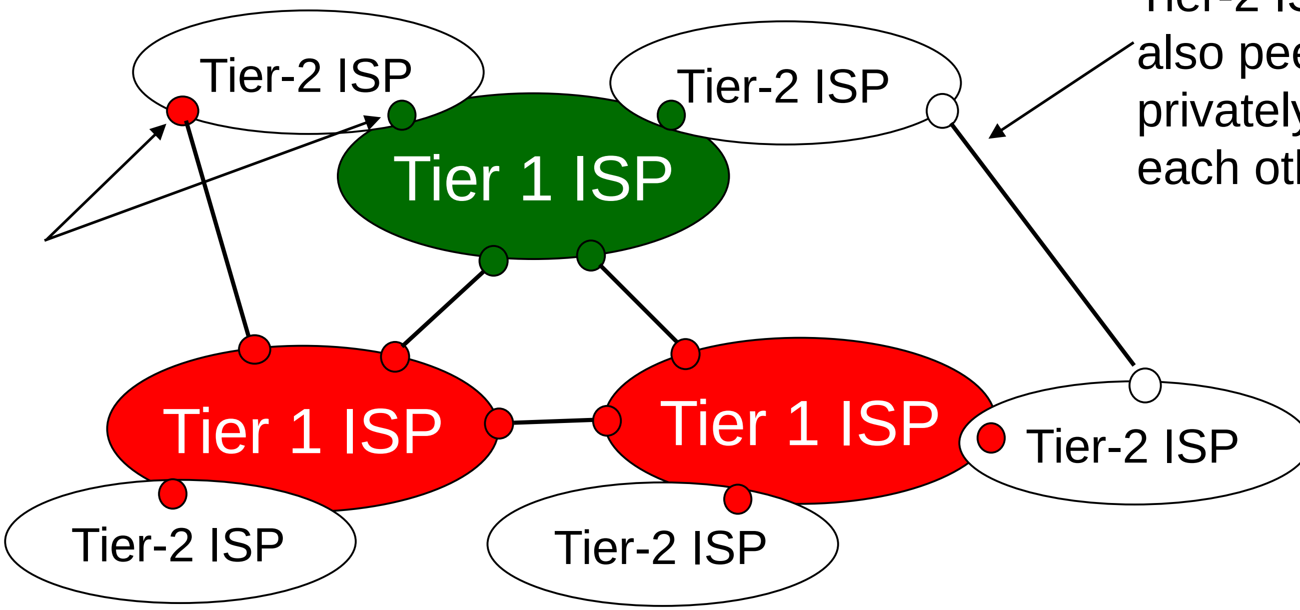
Tier-1 ISP: e.g., Sprint



Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is *customer* of tier-1 provider

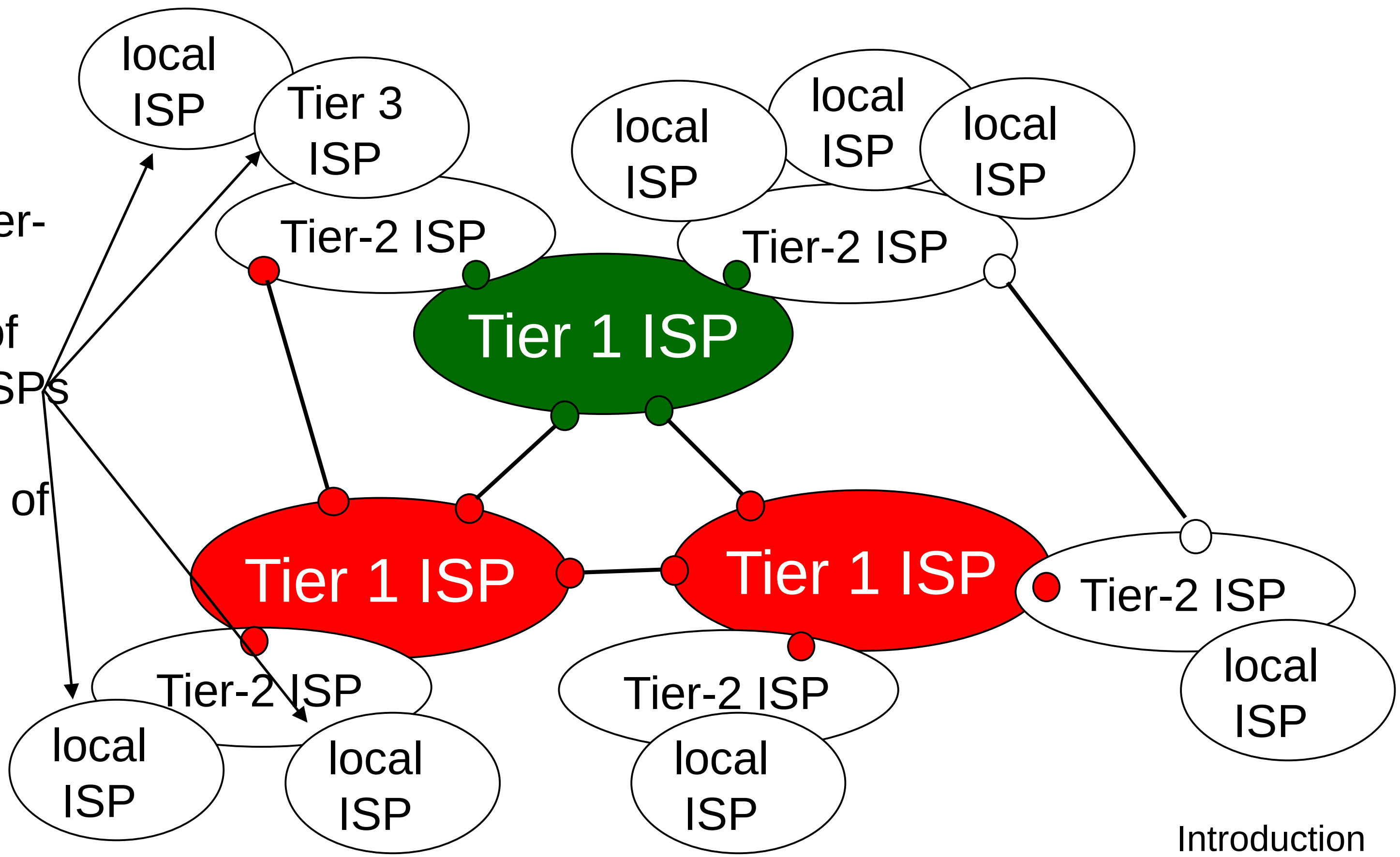


Tier-2 ISPs also peer privately with each other.

Internet structure: network of networks

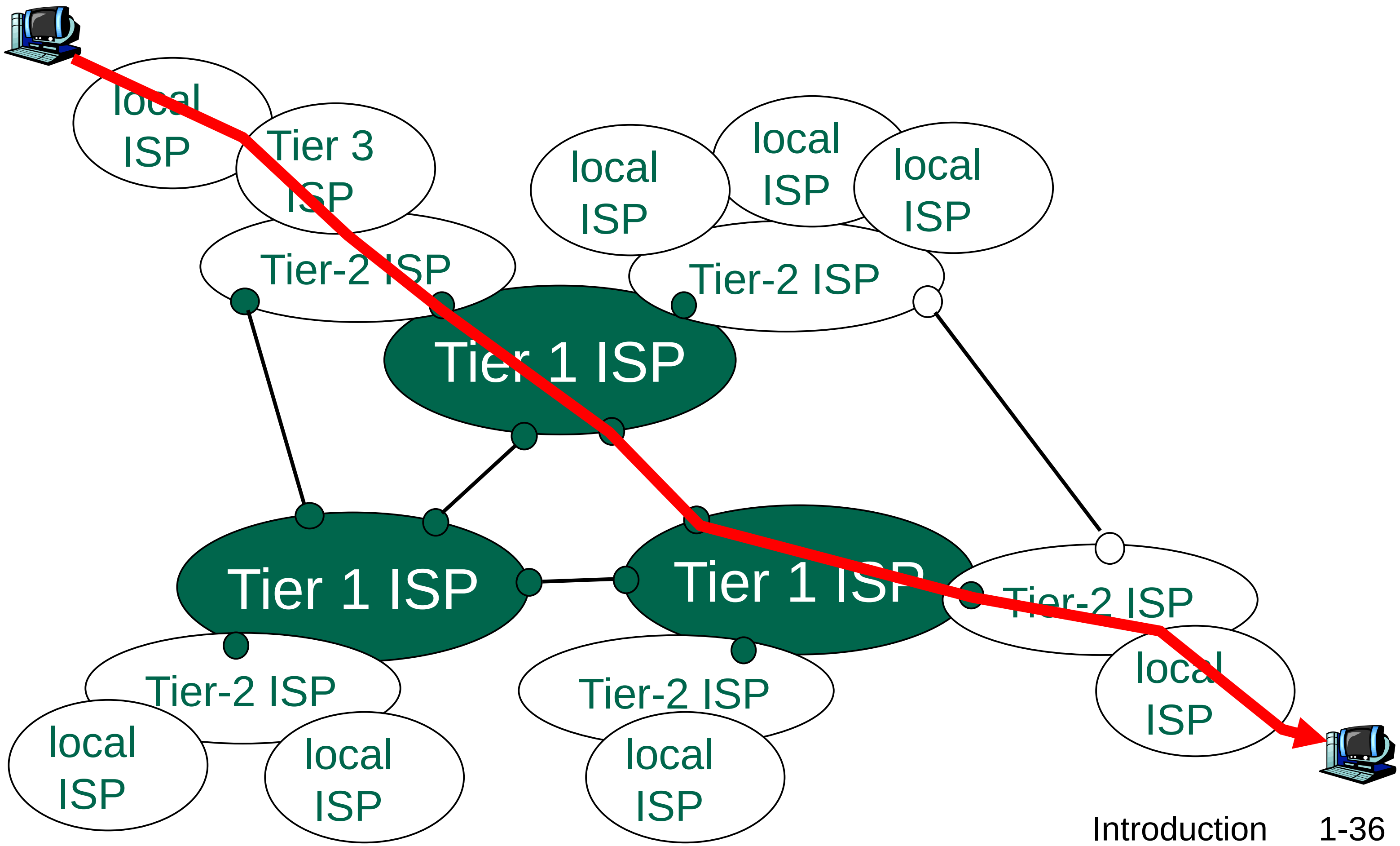
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



Internet structure: network of networks

- a packet passes through many networks!



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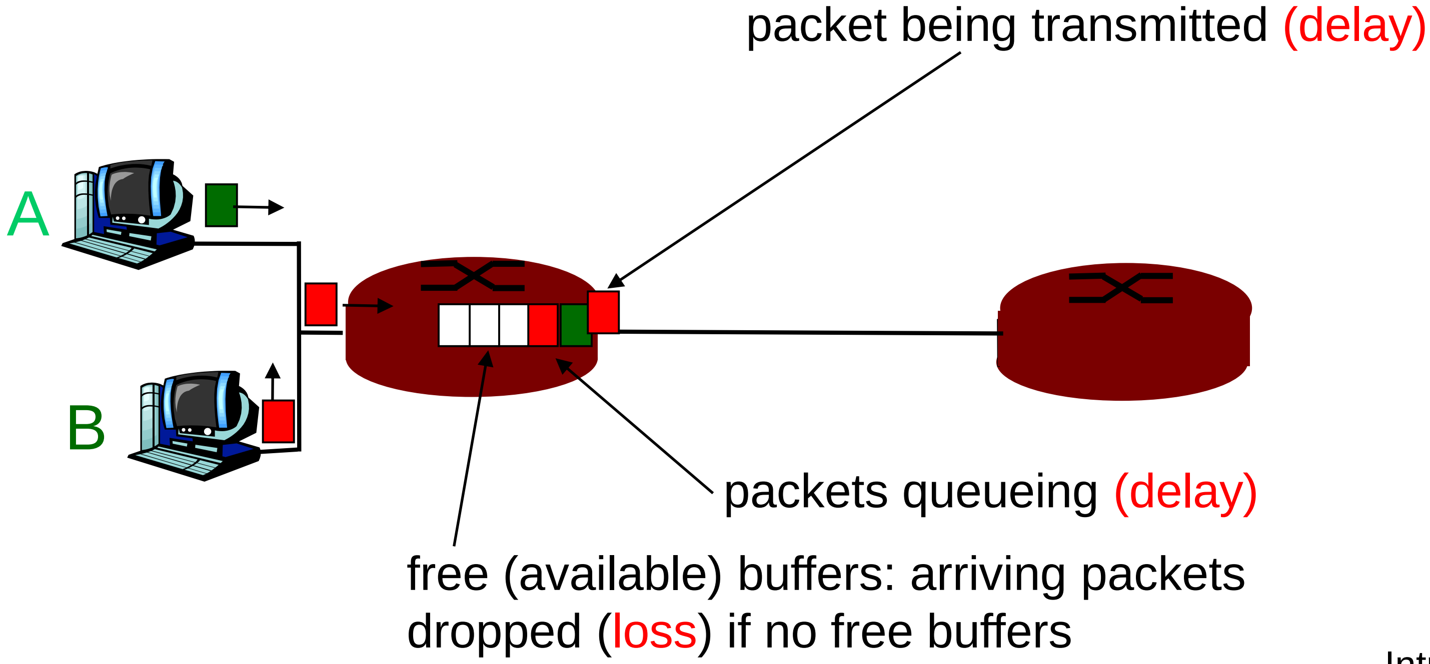
How do loss and delay occur?

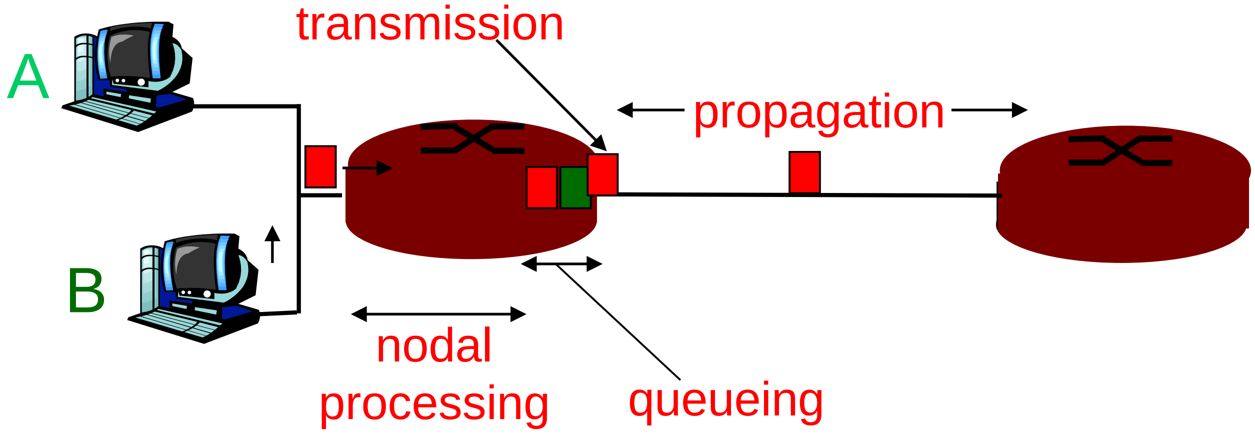
packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router

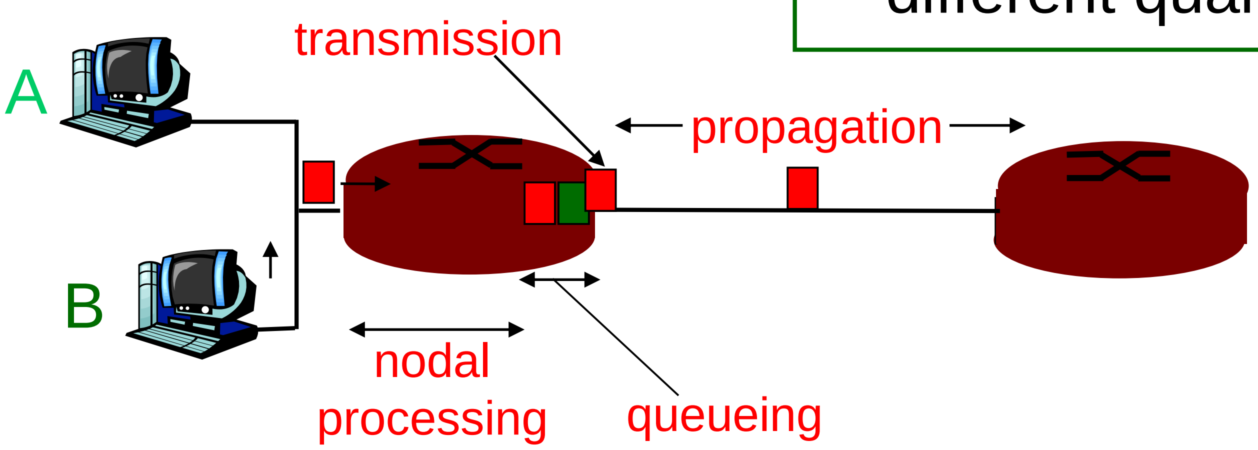


Delay in packet-switched networks

3. Transmission delay:
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

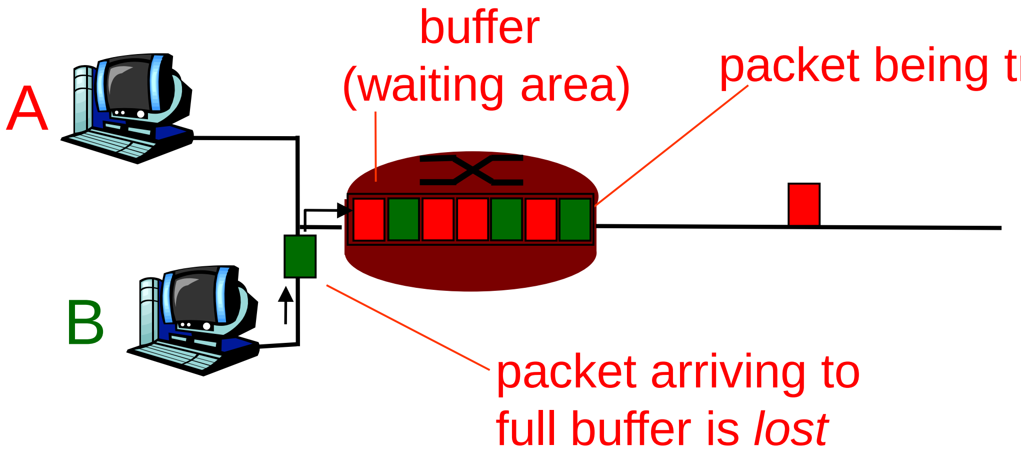
4. Propagation delay:
- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!



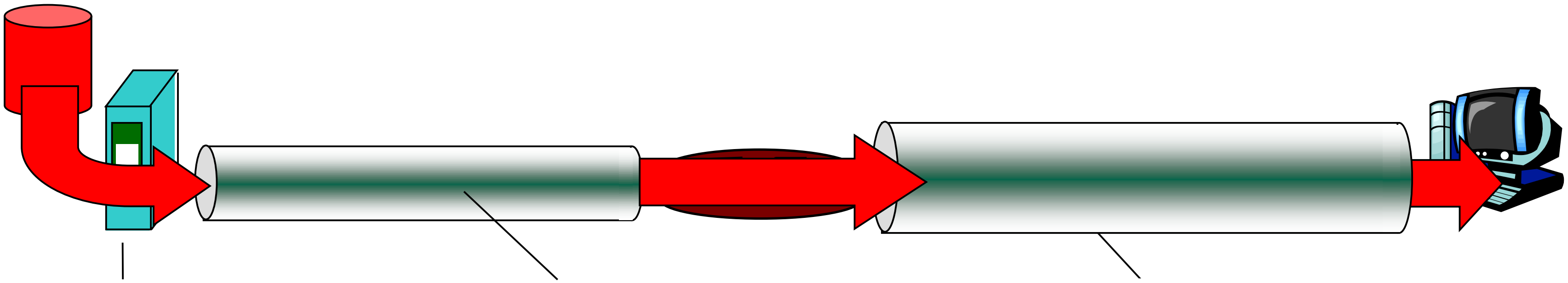
Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



Throughput

- *throughput:* rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



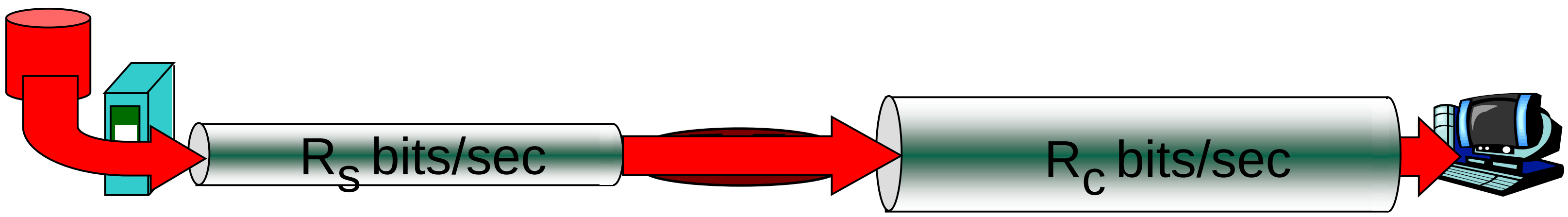
server sends bits (fluid) into pipe

pipe that can carry fluid at rate R_s bits/sec)

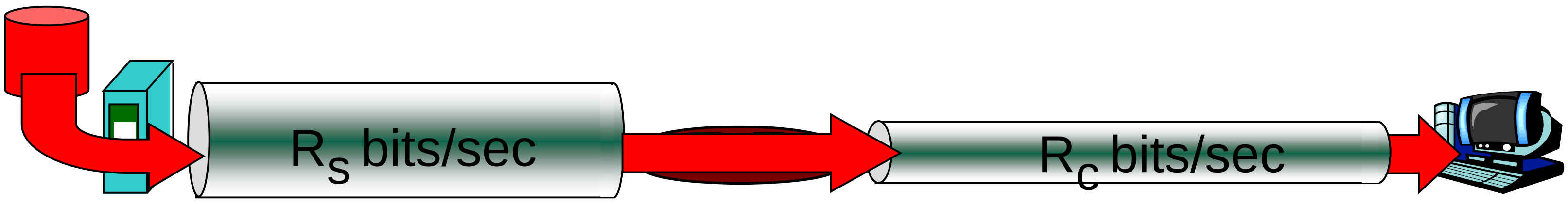
pipe that can carry fluid at rate R_c bits/sec)

Throughput (more)

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

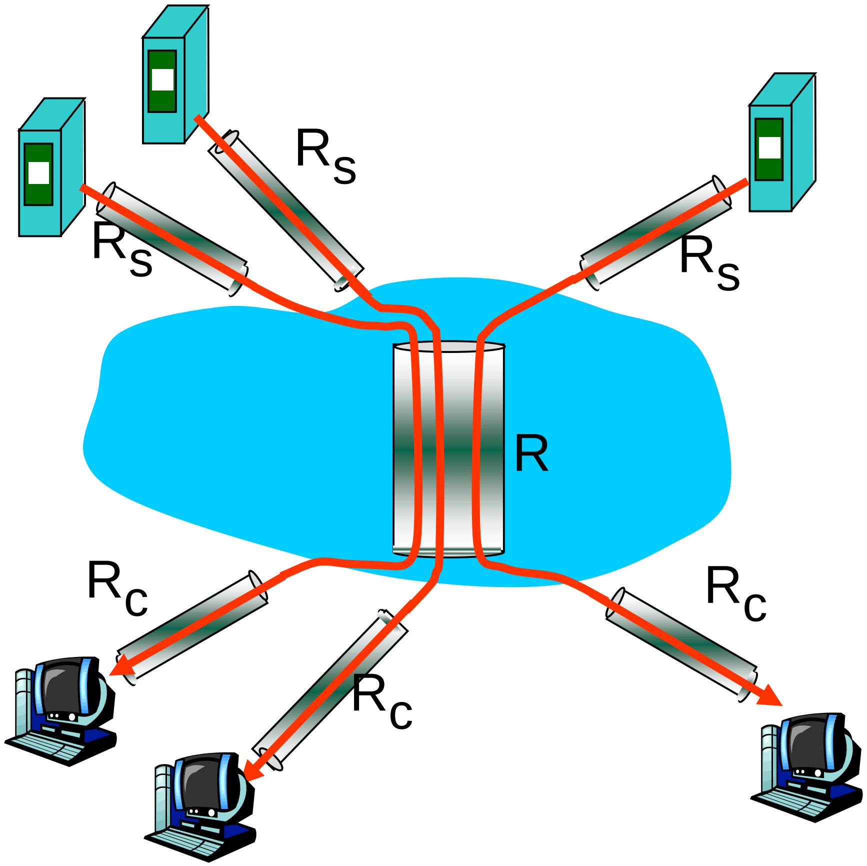


bottleneck link

link on end-end path that constrains end-end throughput

Throughput: Internet scenario

- per-connection end-end throughput: $min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link R bits/sec

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Protocol "Layers"

Networks are complex!

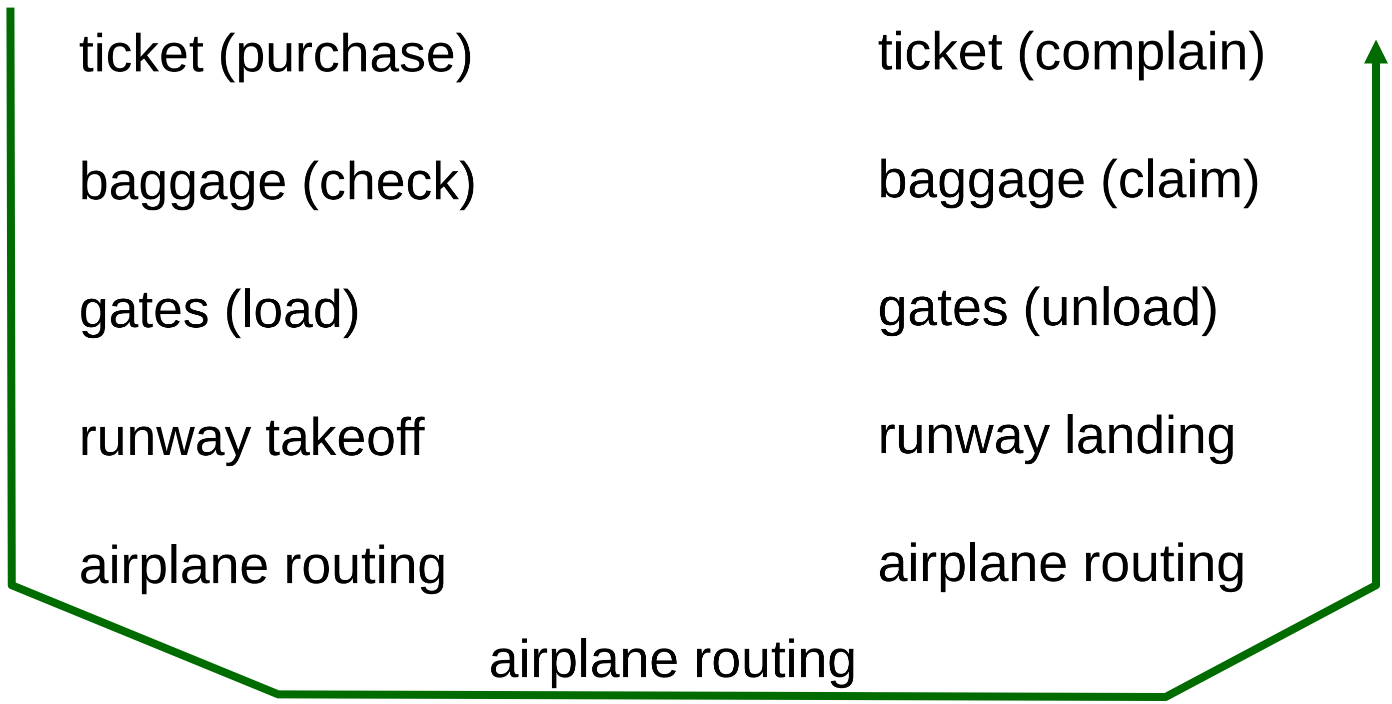
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

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

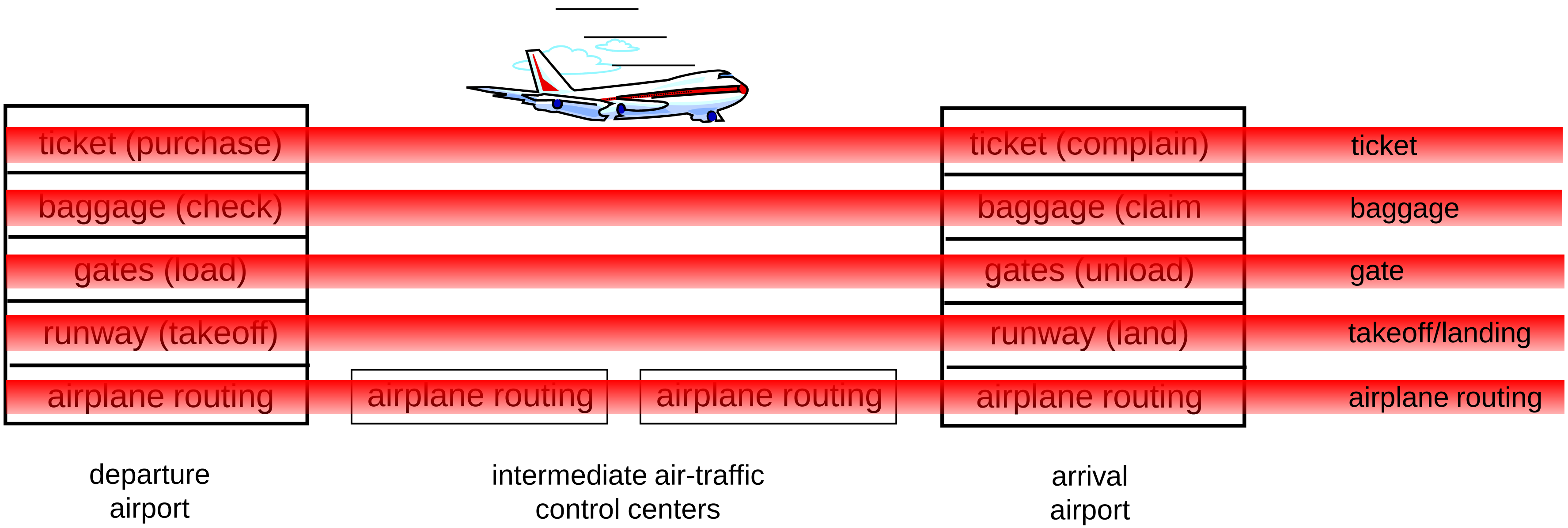
Or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



Layers: each layer implements a service

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

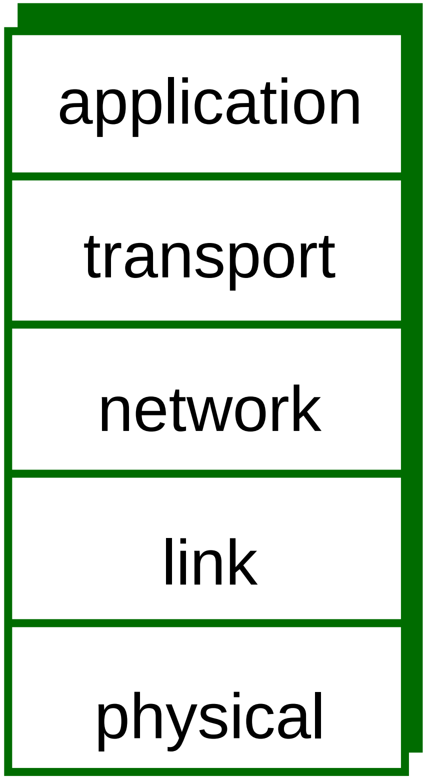
Why layering?

Dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?

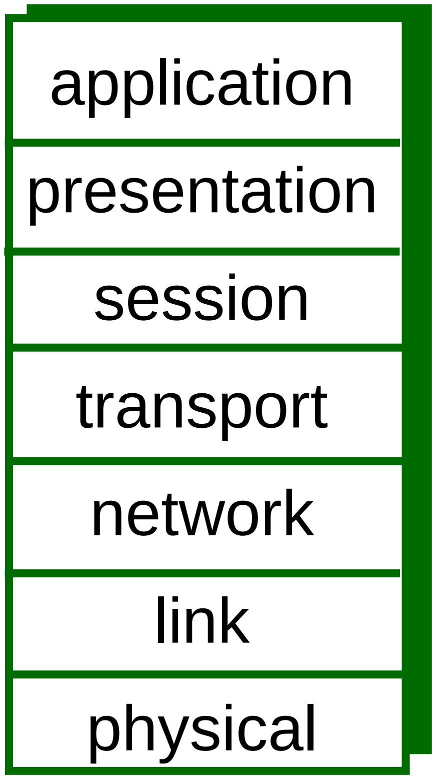
Internet protocol stack

- 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
  - PPP, Ethernet
- physical: bits “on the wire”

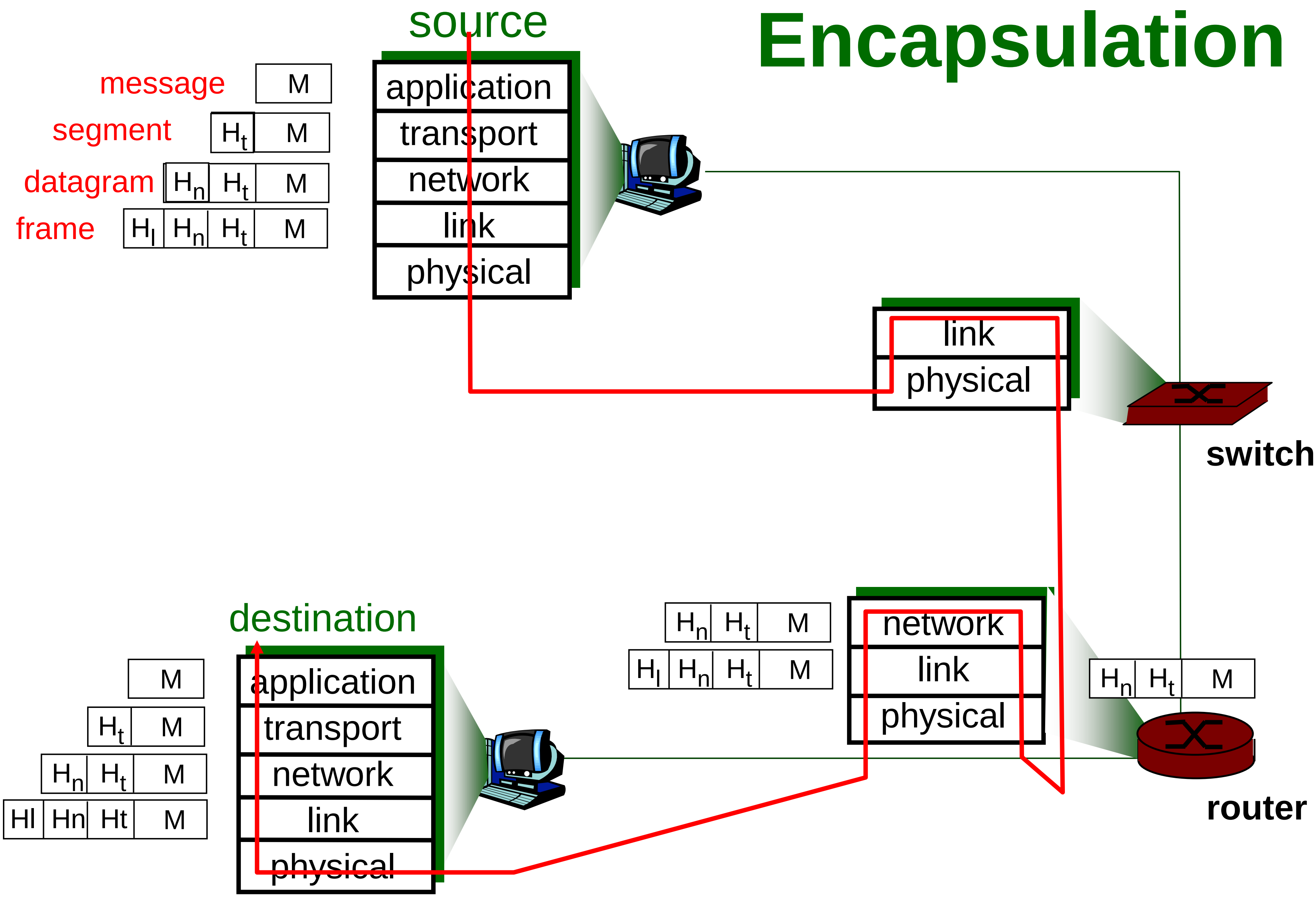


ISO/OSI reference model

- 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?



Encapsulation



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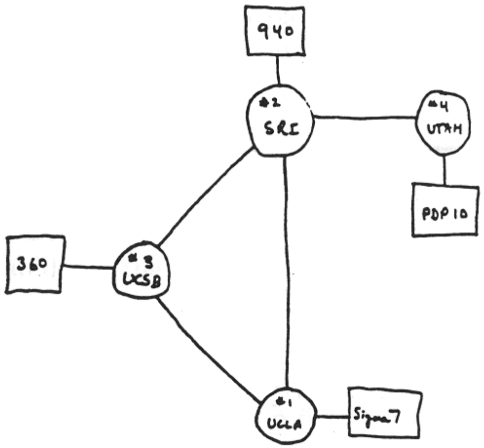
Internet History

1961-1972: 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
- 1972:
  - ARPAnet public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- ate70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1980-1990: 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

Internet History

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 host, 100 million+ users
- backbone links running at Gbps

Internet History

2015:

- 40% of world population has access to Internet
- 1 billion websites online
- Largest traffic creators: YouTube, NetFlix, etc.
- Moved to wireless network, mobility
- 1,200 billion search requests towards Google

Introduction: Summary

Covered a “ton” of material!

- Internet overview
  - Incl. Internet / ISP strucuture
- what’s a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- history

You (should ;) now have:

- context, overview, “feel” of networking
- more depth, detail *to follow!*