Netzwerktechnik und IT-Netze

Chapter 1: Computer Networks and the Internet

Vorlesung im WS 2017/2018

Bachelor Informatik

(3. Semester)

Prof. Dr. rer. nat. Andreas Fischer

Fakultät für Elektrotechnik, Medientechnik und Informatik

Overview

- Introduction
- Computer Networks and the Internet
- Application Layer
  - WWW, Email, DNS, and more
  - Socket programming
- Transport Layer
- Network Layer
- Link Layer
- P2P Networks

Prof. Dr. rer. nat. Andreas Fischer – http://@ndreas.de

Kontakt Dozent

Prof. Dr. Andreas Fischer
Email: andreas.fischer@th-deg.de
Tel: 0991/3615-653
Sprechzeiten nach Vereinbarung per Mail
Raum: E 230

Ablauf der Vorlesung

- 2 Stunden Vorlesung
  - Theoretisches Wissen
  - PowerPoint-Präsentation
- 2 Stunden Praktikum
  - Praktische Übungen
  - Vertiefung des Wissen
- Insgesamt 14 Veranstaltungen
  - **Anwesenheit und Mitarbeit sind notwendig!**

- Klausur: 90 Minuten schriftliche Prüfung
  - Hilfsmittel: Ein einseitig handschriftlich beschriebenes DIN A4 Blatt

Ablauf der Vorlesung

- Nutzung von iLearn
  - Materialien, Beispiele, Vorlesungsfolien
  - Übungsaufgaben und Musterlösungen
  - Diskussionsforum
  - **Bekanntmachung von kurzfristigen Verschiebungen**
  - **https://ilearn.th-deg.de/**
  - **Kurs: AI3 – Netzwerktechnik und IT-Netze (AI3NUITN1718)**
  - **Passwort: NETZ2017**
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Overview

- Introduction
- Computer Networks and the Internet
- Application Layer
  - WWW, Email, DNS, and more
  - Socket programming
  - Web service
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- Link Layer
- P2P Networks

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Welches Vorwissen bringen Sie mit?

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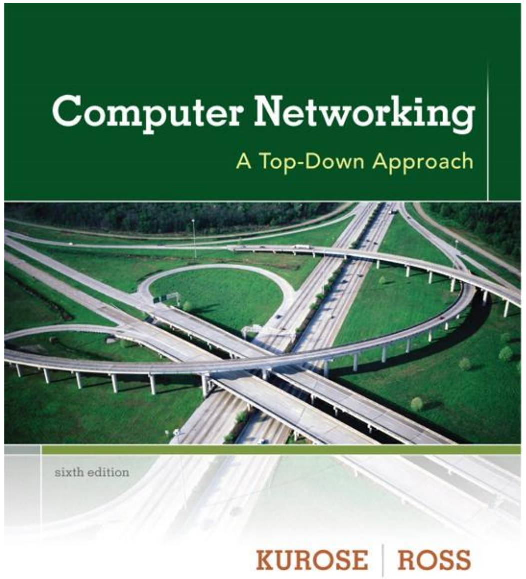
Introduction

- A note on the use of these power point slides:
  -
  - Do not copy or distribute this slide set!



Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

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Introduction

- Our goal:
  - Get "feel" and terminology
  - More depth, detail later in course
  - Approach:
    - Use internet as example
- Overview
  - What's the internet?
  - What's a protocol?

- Network edge; hosts, access net, physical media
- Network core: packet / circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

Chapter 1: Roadmap

- What is the Internet?
- Network edge
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  - Packet switching, circuit switching, network structure
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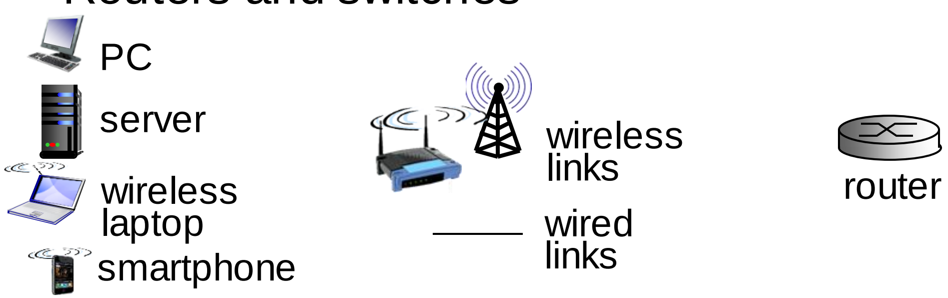
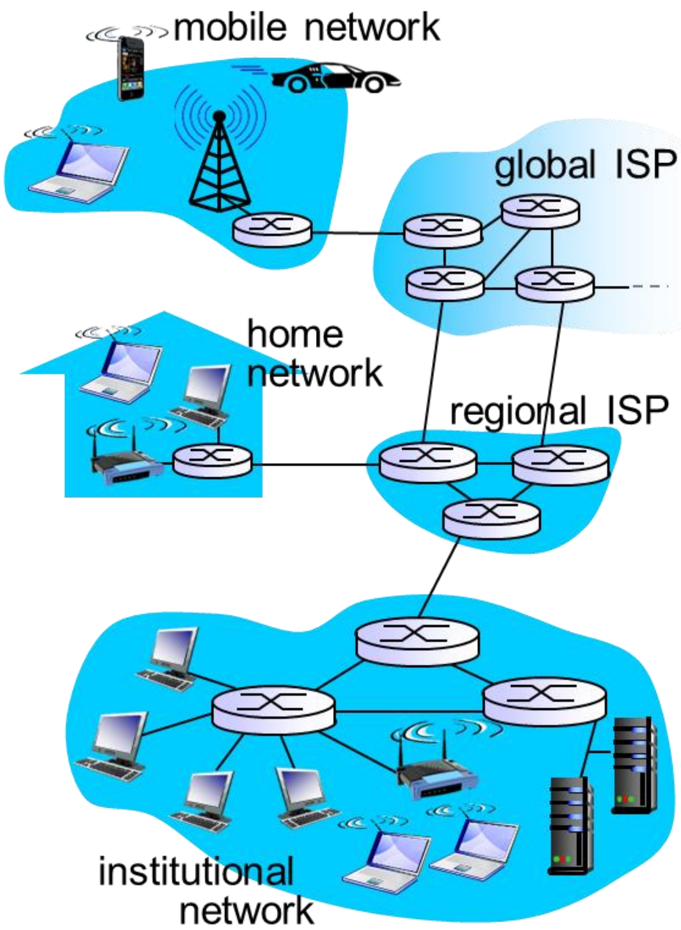
What's the Internet: "nuts and bolts" view

- Millions of connected computing devices:
  - Hosts = end systems
  - Running network apps
- Communication links
  - Fiber, copper, radio, satellite
  - Transmission rate: bandwidth
- Packet switches: forward packets (chunks of data)
  - Routers and switches





“Fun” internet appliances

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

Web-enabled
toaster +
weather forecaster

Tweet-a-watt:
monitor energy
use

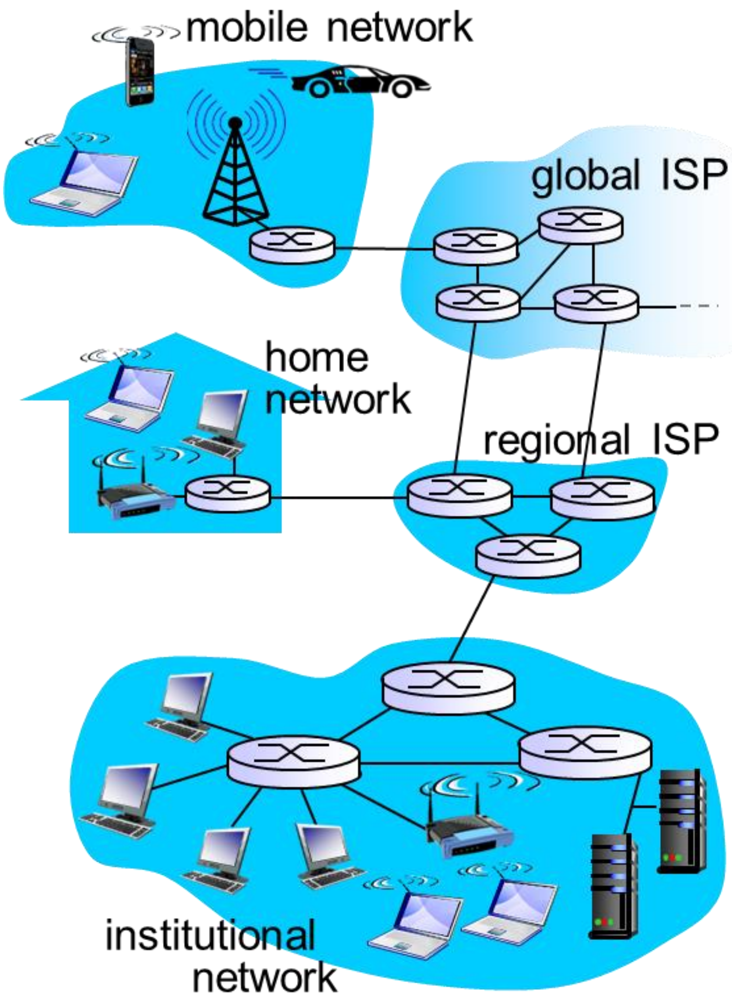
Internet
refrigerator

Slingbox: watch,
control cable TV
remotely

Internet
phones

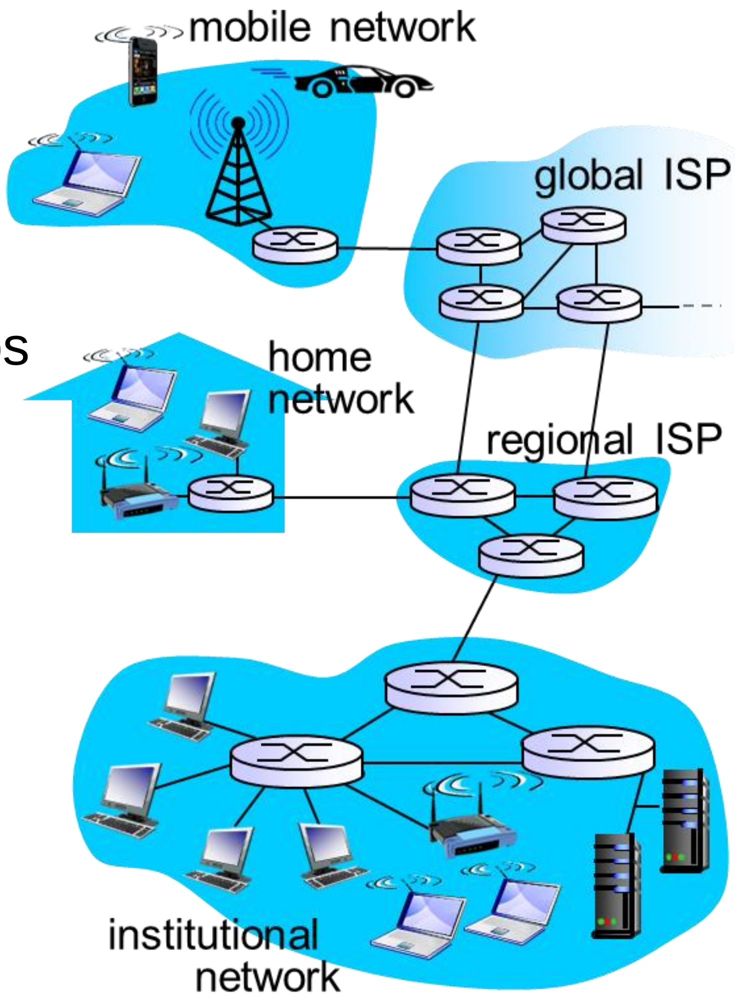
What's the Internet: "nuts and bolts" view

- Internet: "network of networks"
  - Interconnected ISPs
- Protocols control sending, receiving of Msgs
  - E.g., TCP, IP, HTTP, Skype, 802.11
- Internet standards
  - RFC: Request For Comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- Infrastructure that provides services to applications:
  - Web, VoIP, email, games, e-commerce, social nets, …
- Provides programming interface to apps
  - Hooks that allow sending and receiving app programs to "connect" to internet
  - Provides service options, analogous to postal service



What’ s a protocol?

- Human protocols:
  - “What’s the time?”
  - “I have a question”
  - Introductions

…..Specific messages sent

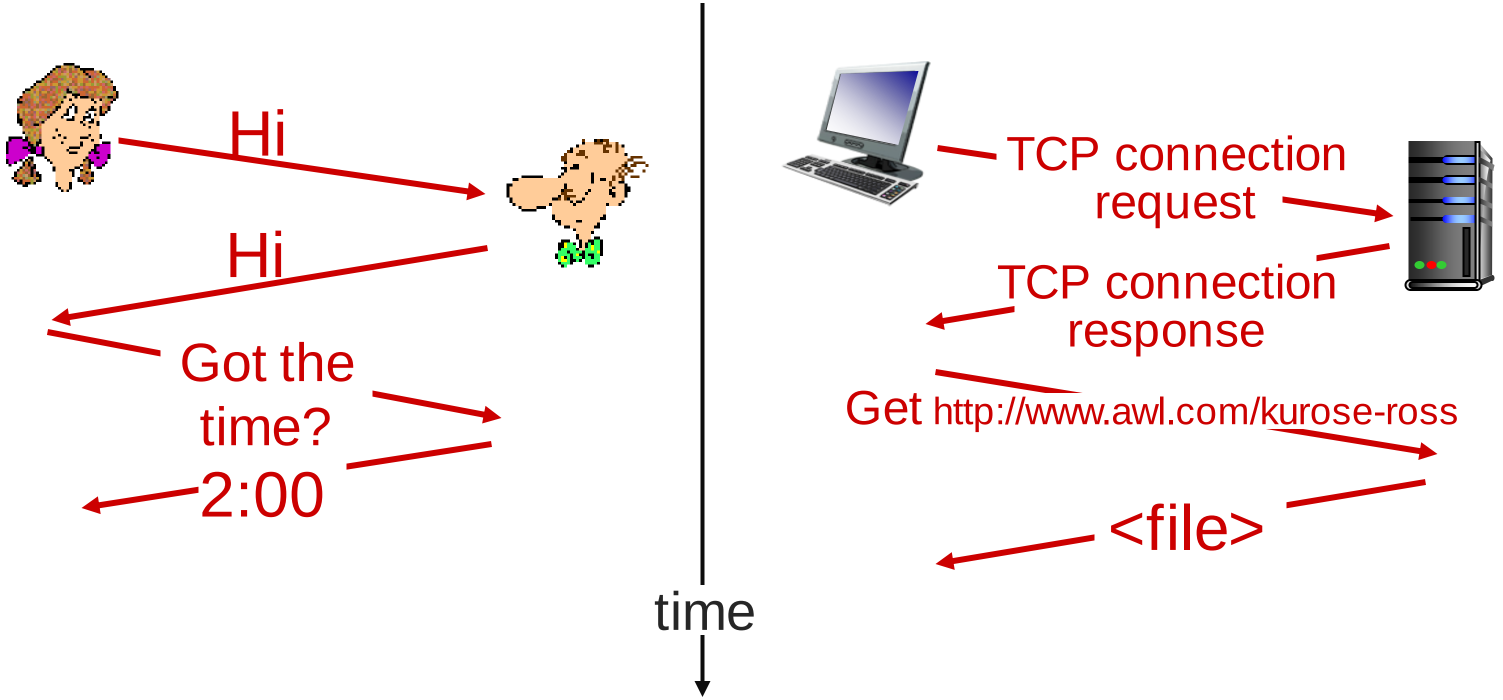
……Specific actions taken when messages received, or other events

- Network protocols:
  - Machines rather than humans
  - All communication activity in internet governed by protocols

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

What's a protocol?

- A human protocol and a computer network protocol:



Q: other human protocols?

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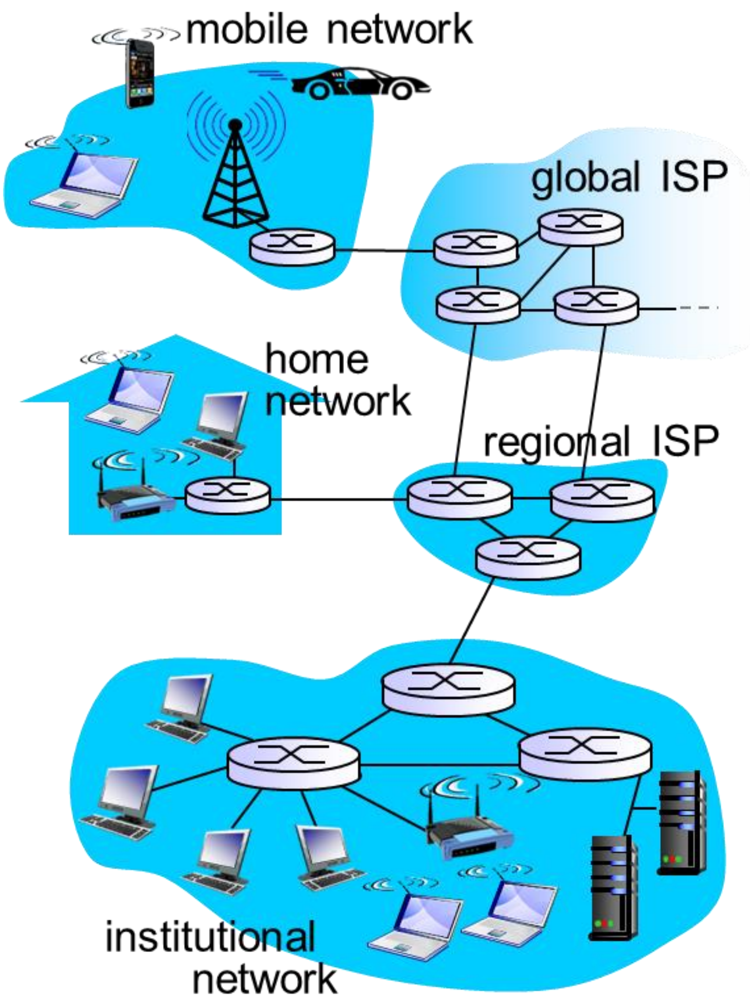
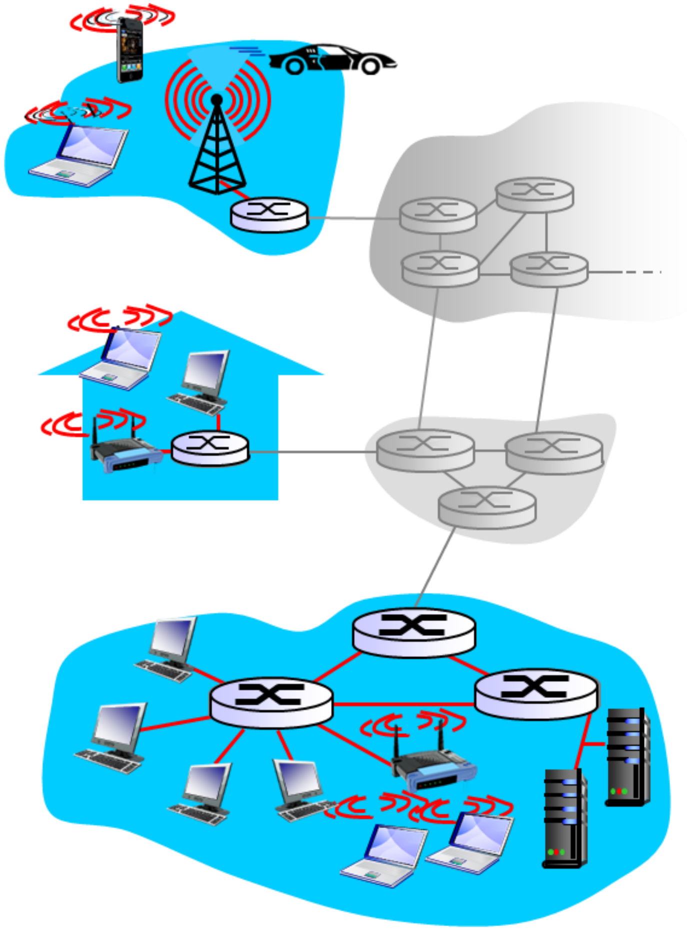
A closer look at network structure:

- Network edge:
  - Hosts: clients and servers
  - Servers often in data centers
- Access networks, physical media:
  - Wired, wireless communication links
- Network core:
  - Interconnected routers
  - Network of networks



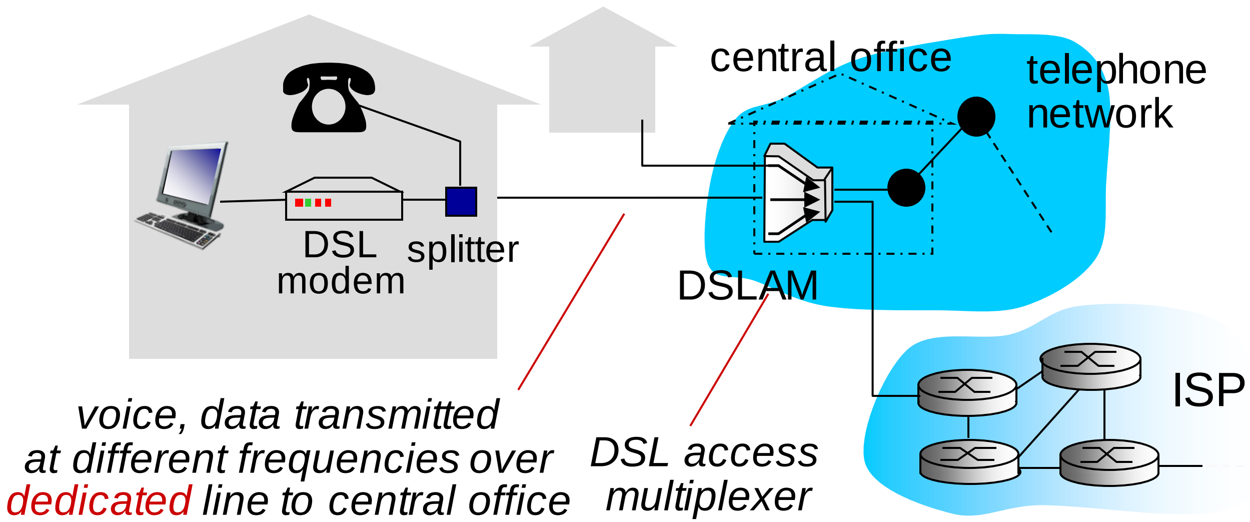
Access networks and physical media

- 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?



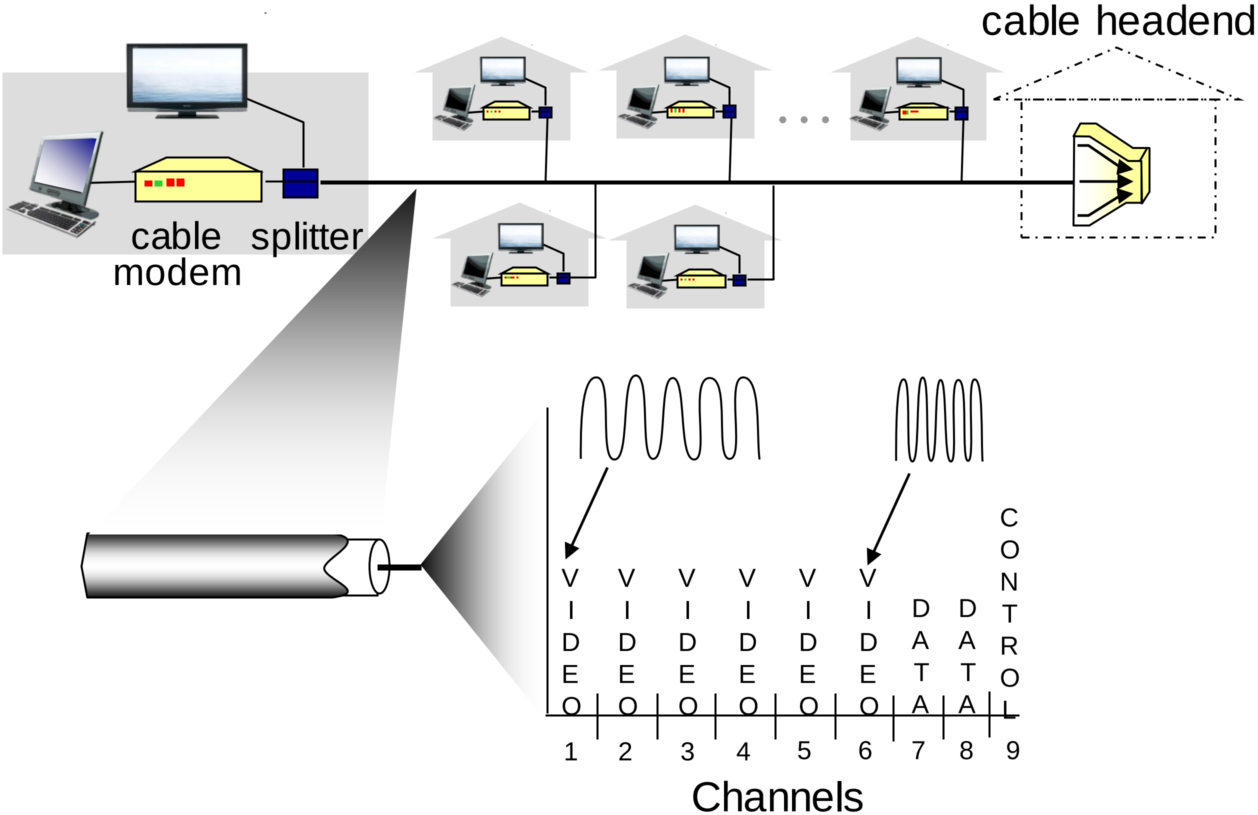
Access net: digital subscriber line (DSL)

- Use existing telephone line to central office DSLAM
  - Data over DSL phone line goes to internet
  - Voice over DSL phone line goes to telephone net
- < 2.5 mbps upstream transmission rate
- < 24 mbps downstream transmission rate



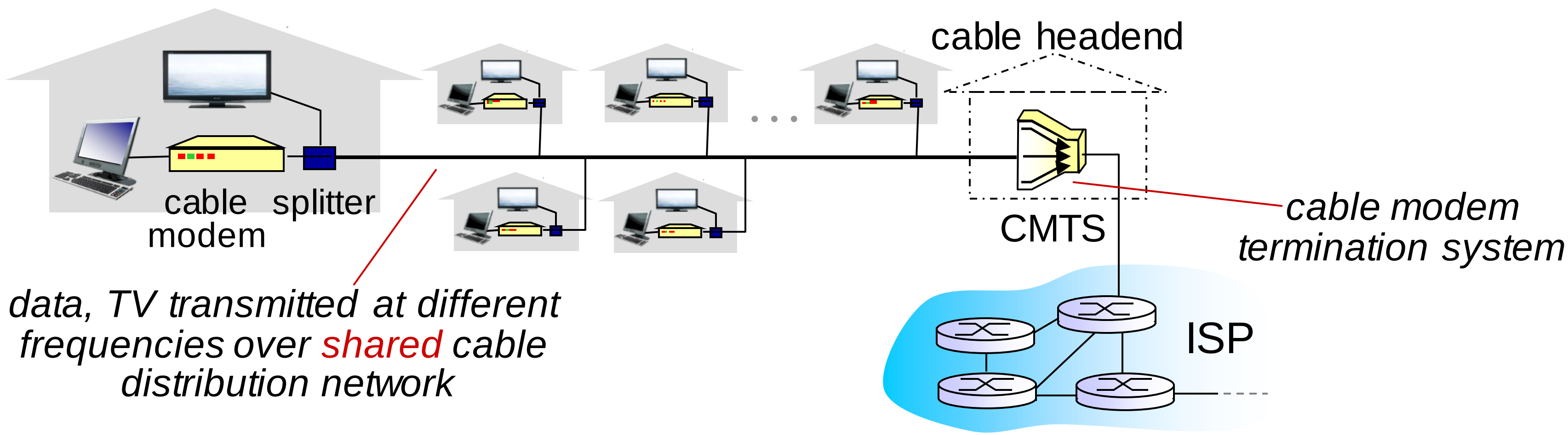
Access net: cable network

- Frequency division multiplexing
  - Different channels transmitted in different frequency bands

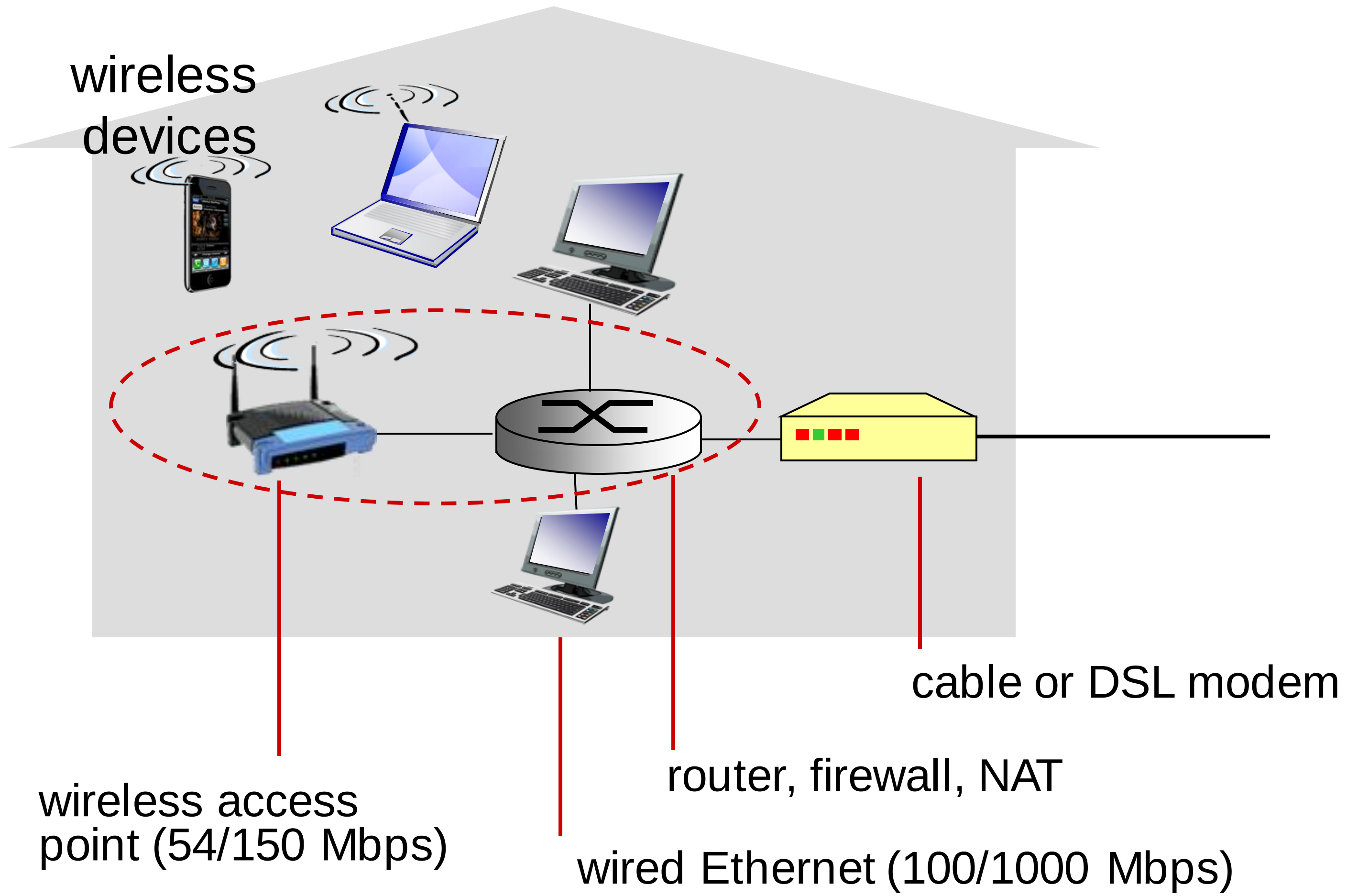


Access net: cable network

- HFC: hybrid fiber coax
  - Asymmetric: up to 30 Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- Network of cable, fiber attaches homes to ISP router
  - Homes share access network to cable headend
  - Unlike DSL, which has dedicated access to central office

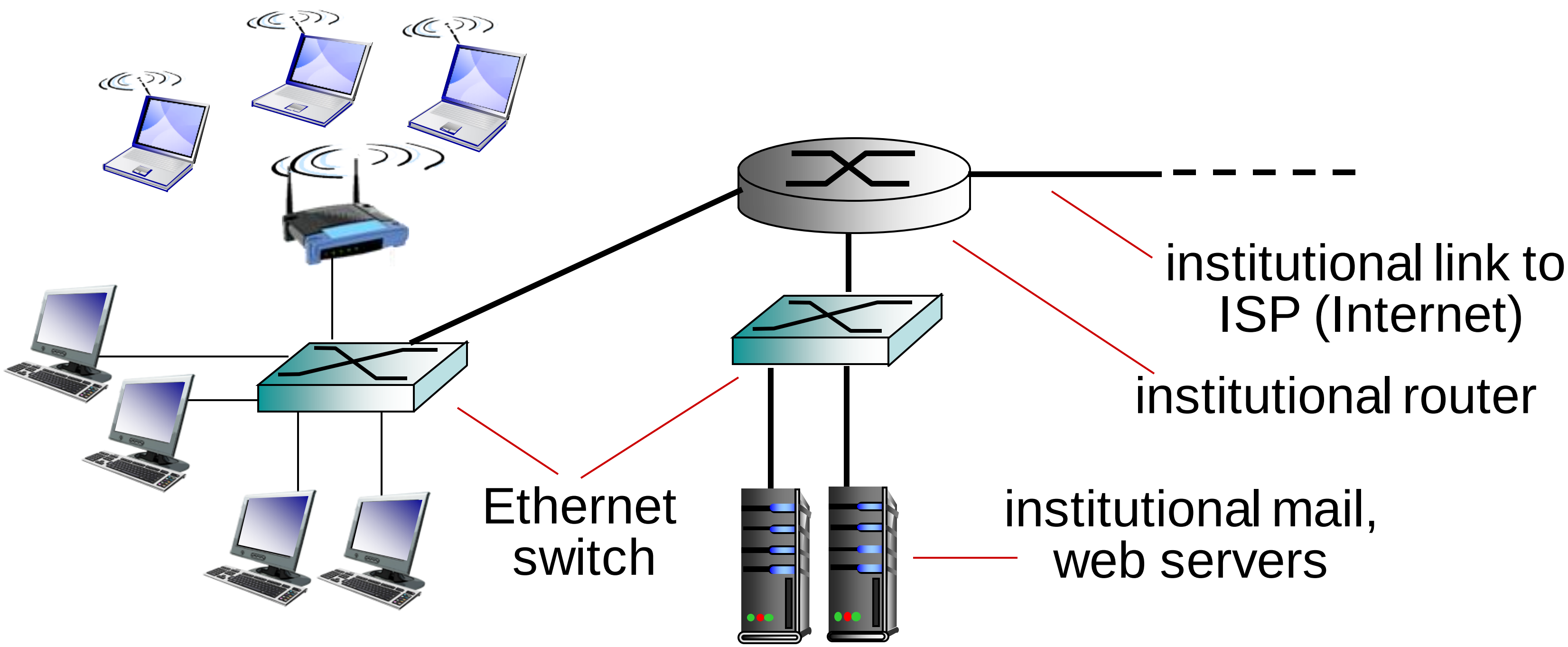


Access net: home network



Enterprise access networks (Ethernet)

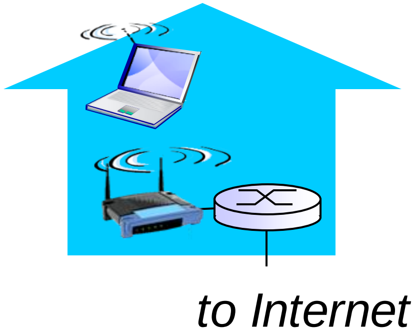
- Typically used in companies, universities, etc.
- 100 Mbps, 1 Gbps, 10 Gbps transmission rates
- Today, end systems typically connect into Ethernet switch



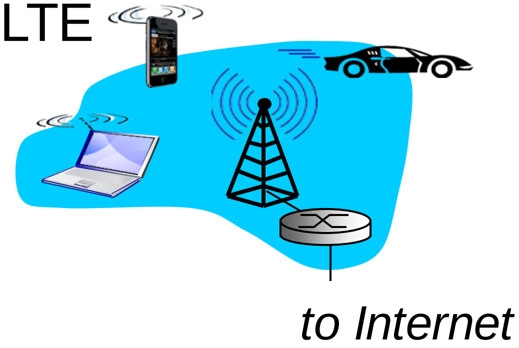
Wireless access networks

- Shared wireless access network connects end system to router
  - Via base station aka "access point"

- Wireless LANs:
  - Within building
  - 802.11ac (WiFi): 150 Mbps transmission rate

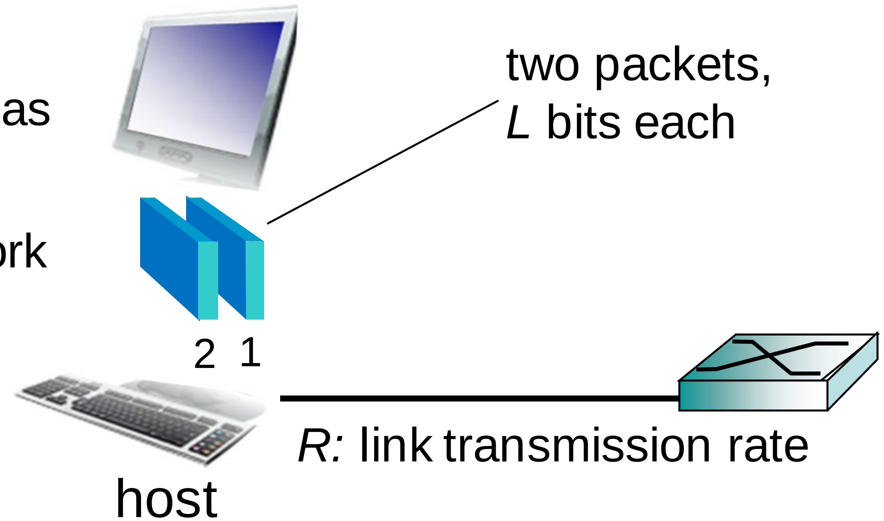


- Wide-area wireless access
  - Provided by telco (cellular) operator, 10's km
  - Between 1 and 10 Mbps
  - 3G, 4G: LTE



Host: sends *packets* of data

- Host sending function:
  - Takes application message
  - Breaks into smaller chunks, known as packets, of length L bits
  - Transmits packet into access network at transmission rate R
    - Link transmission rate,
      aka link capacity, aka link bandwidth



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

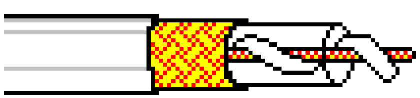
Physical media

- Bit
  - Propagates between transmitter/receiver pairs
- Physical link
  - What lies between transmitter & receiver
- Guided media
  - Signals propagate in solid media: copper, fiber, coax
- Unguided media
  - Signals propagate freely, e.g., Radio
- Twisted pair (TP) : two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10 Gbps

Physical media: coax, fiber

- Coaxial cable:
  - Two concentric copper conductors
  - Bidirectional
  - Broadband:
    - Multiple channels on cable

- Fiber optic cable:
  - Glass fiber carrying light pulses, each pulse a bit
  - High-speed operation:
    - High-speed point-to-point transmission (e.g., 10’s-100’s Gbps transmission rate)
  - Low error rate:
    - Repeaters spaced far apart
    - Immune to electromagnetic noise



Physical media: radio

- Signal carried in electromagnetic spectrum
- No physical “wire”
- Bidirectional
- Propagation environment effects:
  - Reflection
  - Obstruction by objects
  - Interference

- Radio link types
  - Terrestrial microwave
    - E.G. Up to 45 Mbps channels
  - LAN (e.g., WiFi)
    - 11 Mbps, 54 Mbps
  - Wide-area (e.g., Cellular)
    - 3G cellular: ~ few Mbps
  - Satellite
    - Kbps to 45 Mbps channel (or multiple smaller channels)
    - 270 msec end-end delay
    - Geosynchronous versus low altitude

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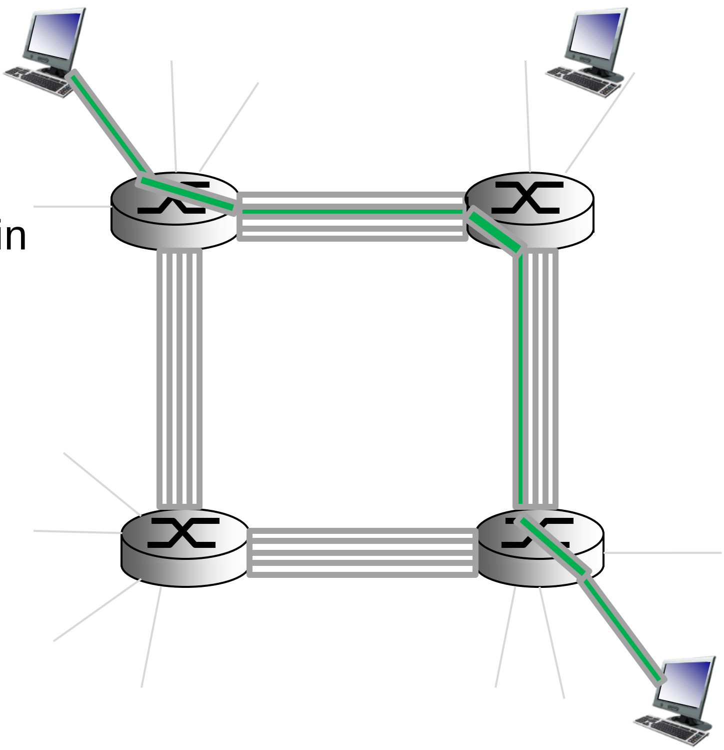
Circuit switching

- End-end resources allocated to, reserved for "call" between source & destination:
  - In diagram, each link has four circuits.
    - Call gets 2nd circuit in top link and 1st circuit in right link.
  - Dedicated resources: no sharing
    - Circuit-like (guaranteed) performance
  - Circuit segment idle if not used by call (no sharing)
  - Commonly used in traditional telephone networks

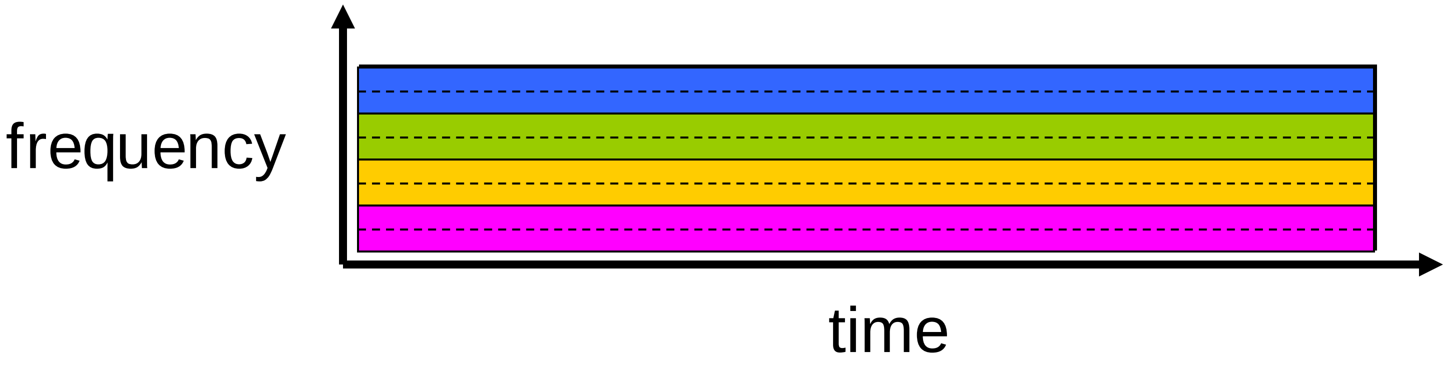


Circuit switching
FDM versus TDM

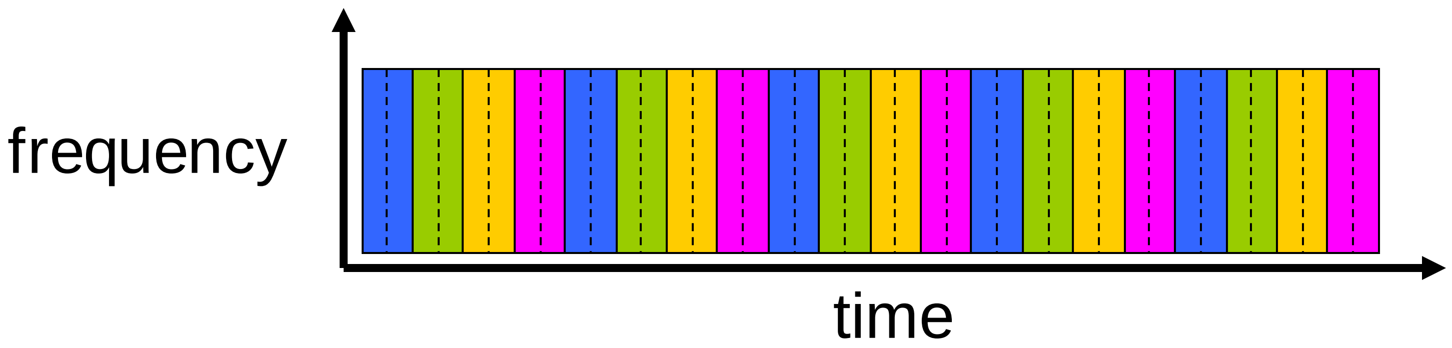
Example:

4 users

FDM

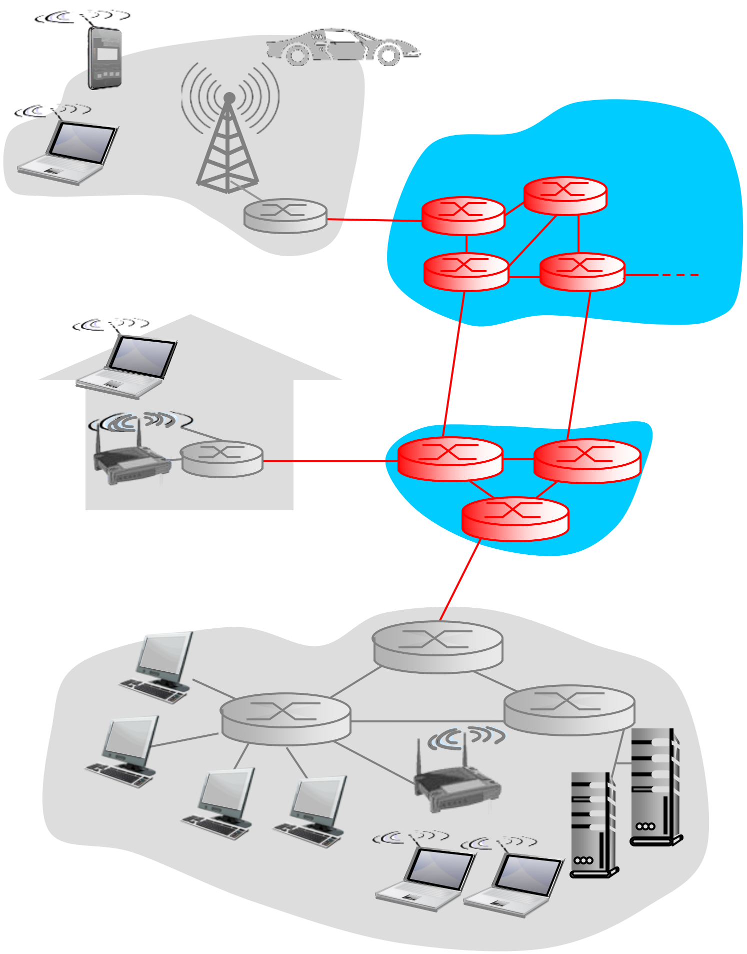


TDM

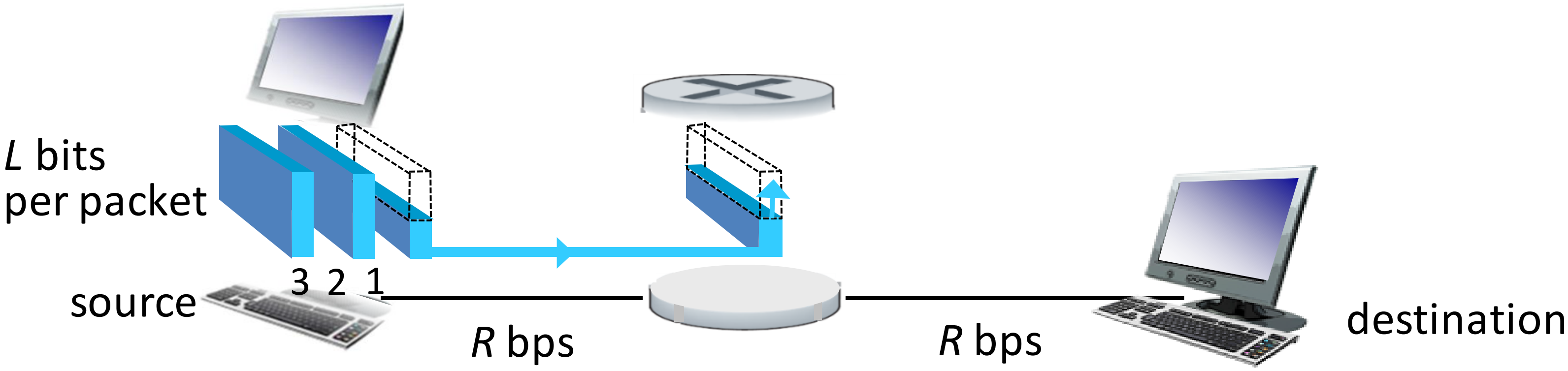


The Internet: Packet switching

- Mesh of interconnected routers
- 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
  - Each packet transmitted at full link capacity



Packet-switching: store-and-forward



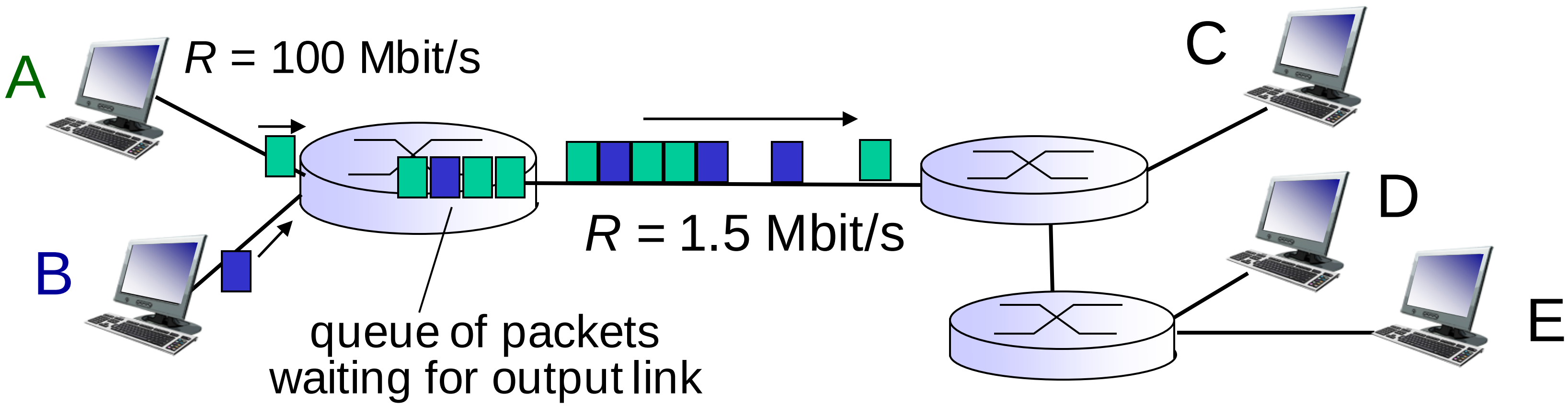
- Takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- **Store and forward**: entire packet must arrive at router before it can be transmitted on next link
- End-end delay = 2L/R (assuming zero propagation delay)

More on delay shortly …

one-hop numerical example:

- *L* = 7.5 Mbit
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec

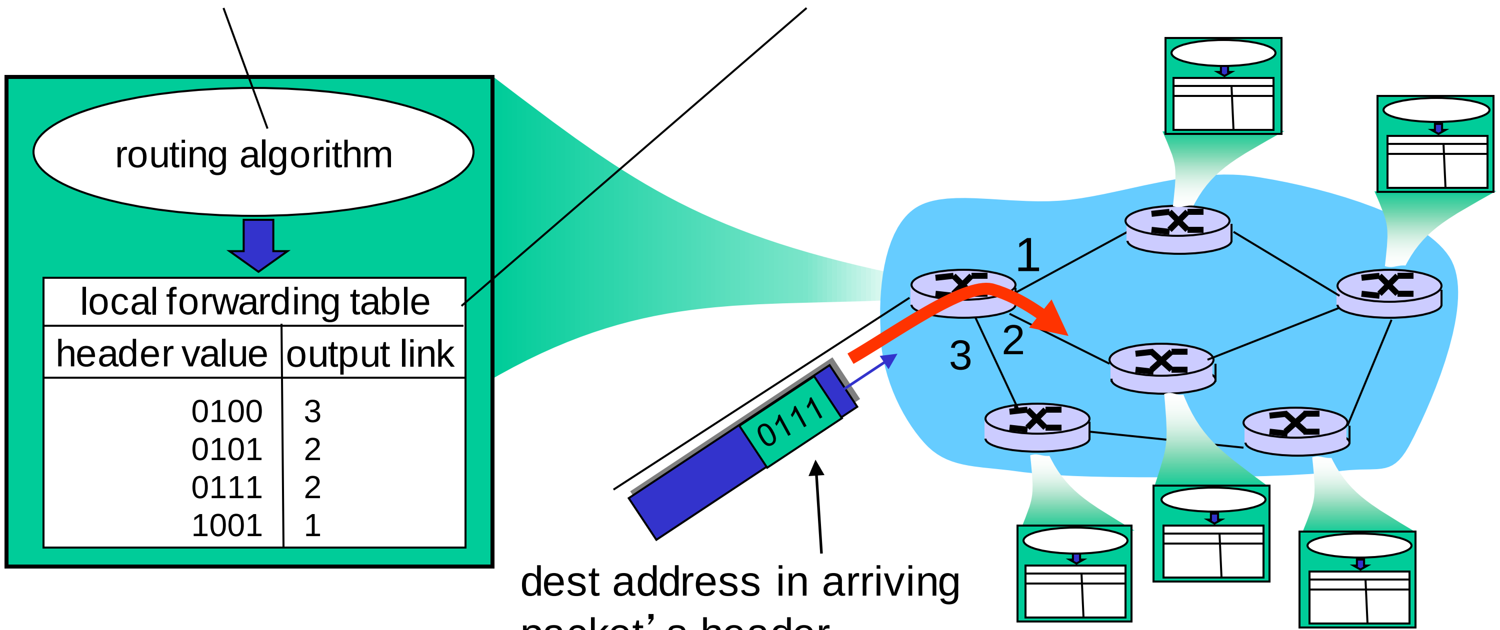
Packet Switching: queueing delay, loss



- Queuing and 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

Two key network-core functions

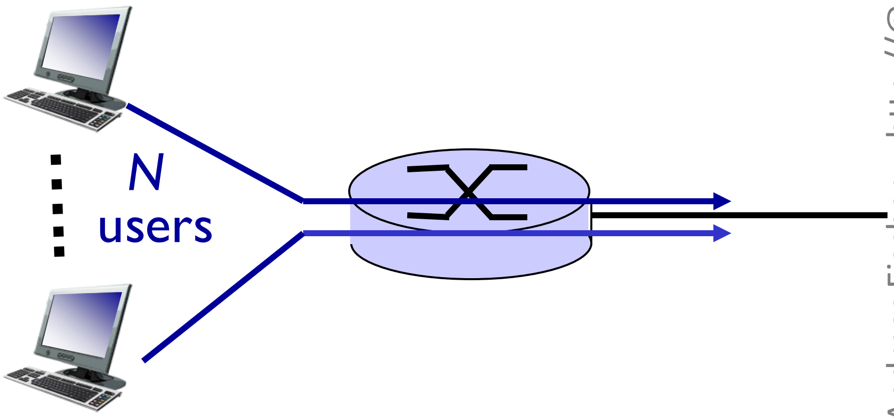
- Routing: determines source-destination route taken by packets
  - Routing algorithms
- forwarding: move packets from router's input to appropriate router output



header value	output link
0100	3
0101	2
0111	2
1001	1

Packet switching versus circuit switching

- Packet switching allows more users to use network!
  - Example:
    - 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 less than 0.0004



Packet switching versus circuit switching

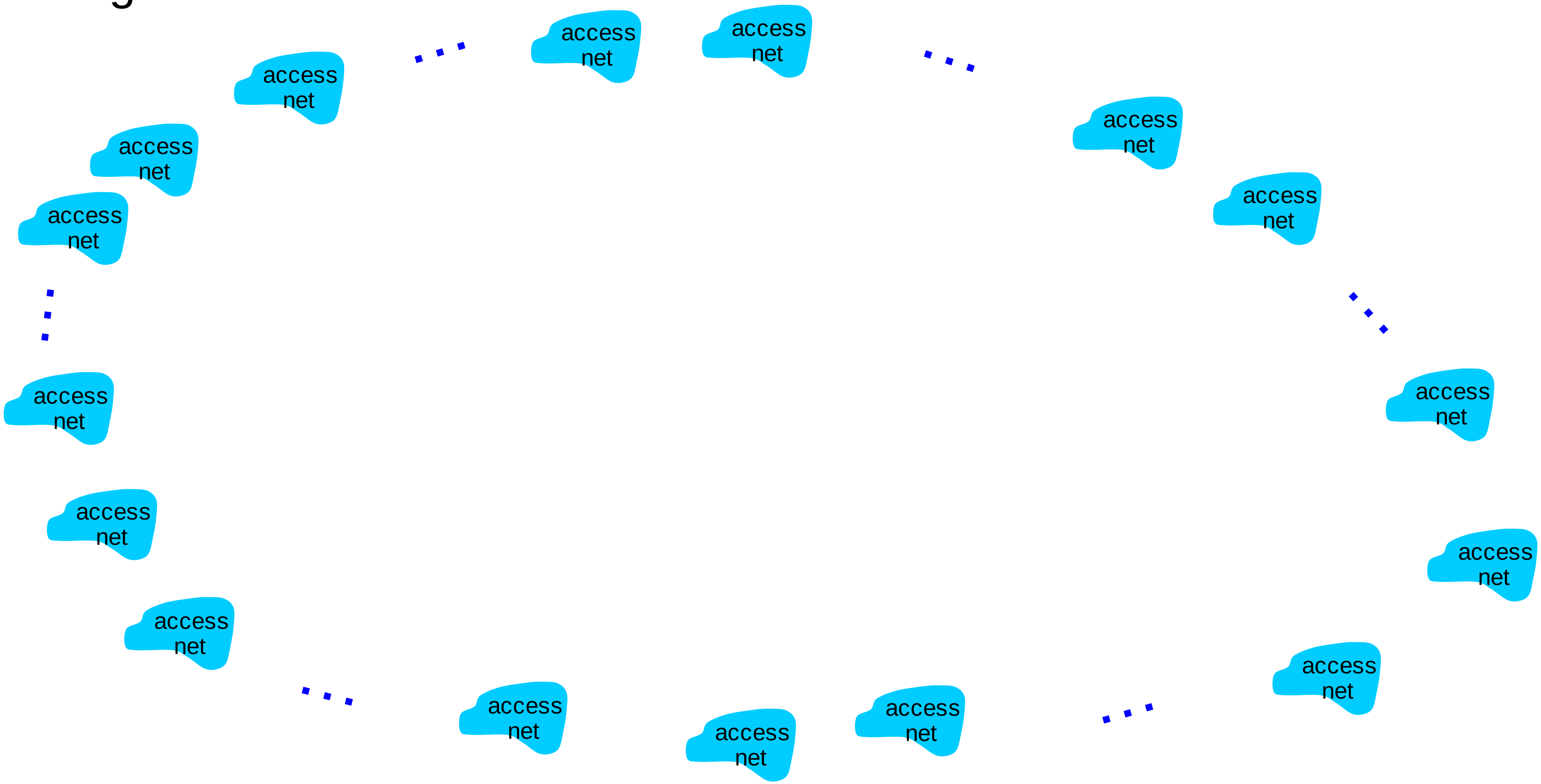
- Is packet switching a “slam dunk winner?”
  - Great for bursty data
    - Resource sharing
    - Simpler, no call setup
  - Excessive congestion possible: packet delay and loss
    - Protocols needed for reliable data transfer, congestion control
- Q: Human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet structure: network of networks

- End systems connect to internet via access ISPs (internet service providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current internet structure

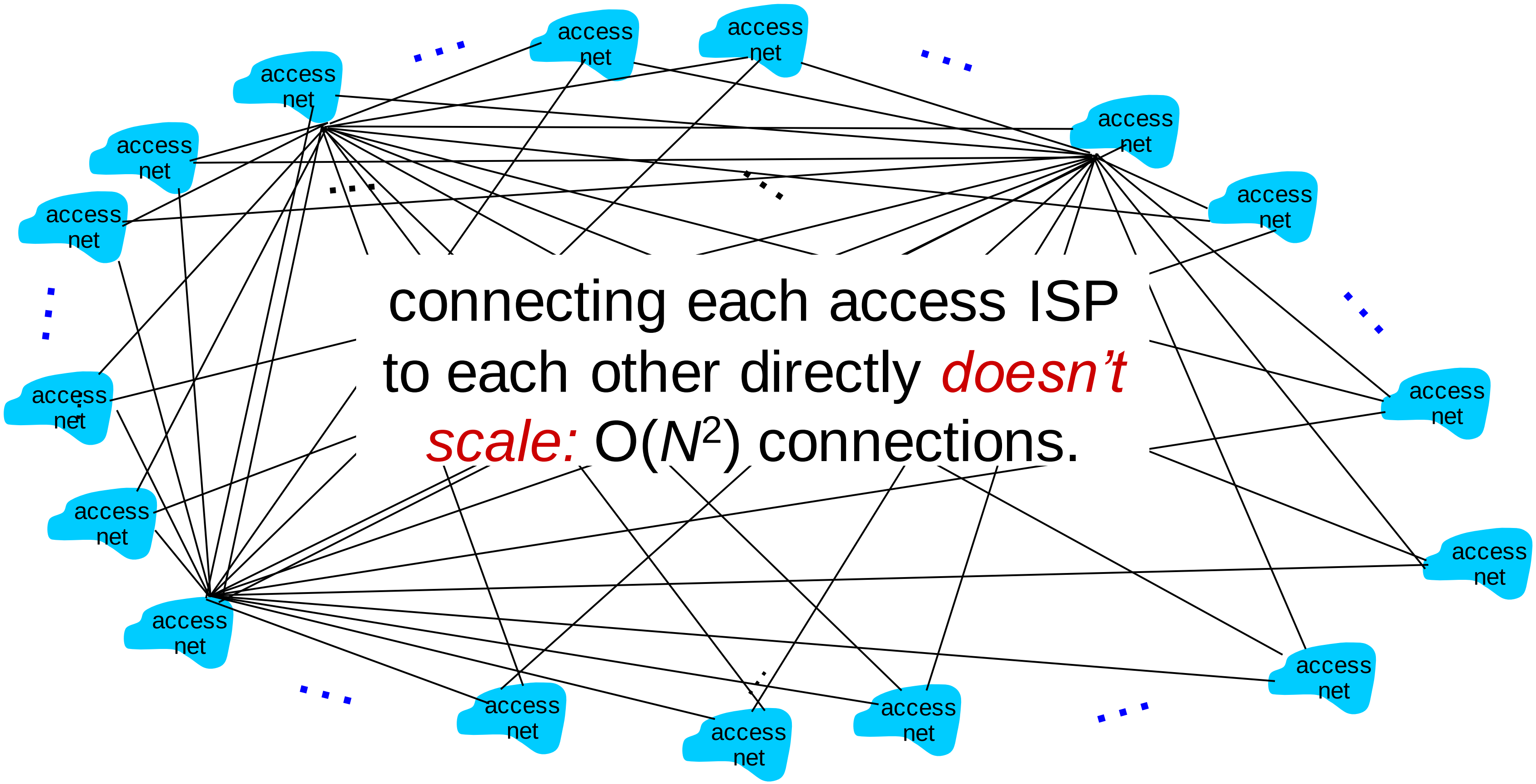
Internet structure: network of networks

- Question: Given millions of access ISPs, how to connect them together?



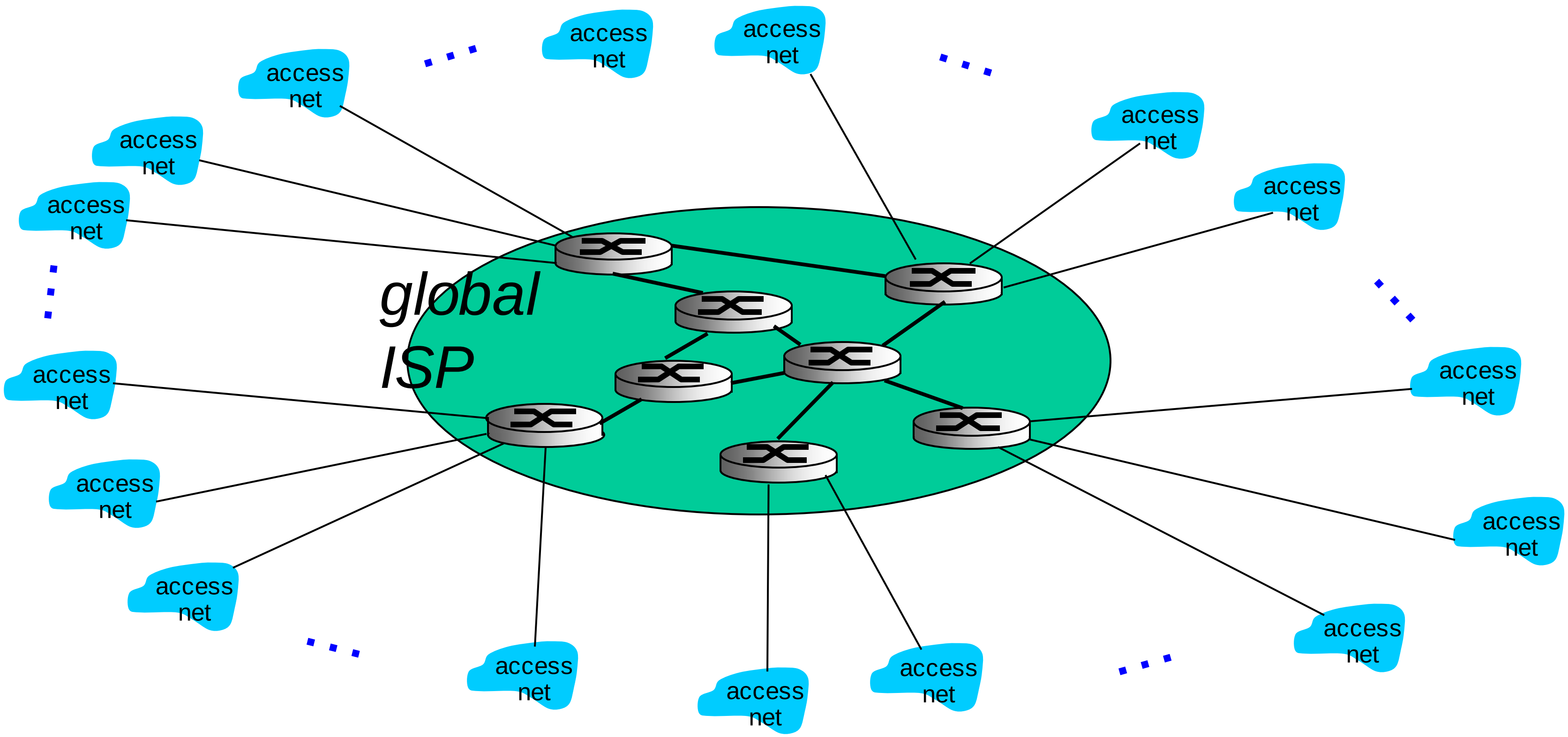
Internet structure: network of networks

- Option: Connect each access ISP to every other access ISP?



Internet structure: network of networks

- Option: Connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



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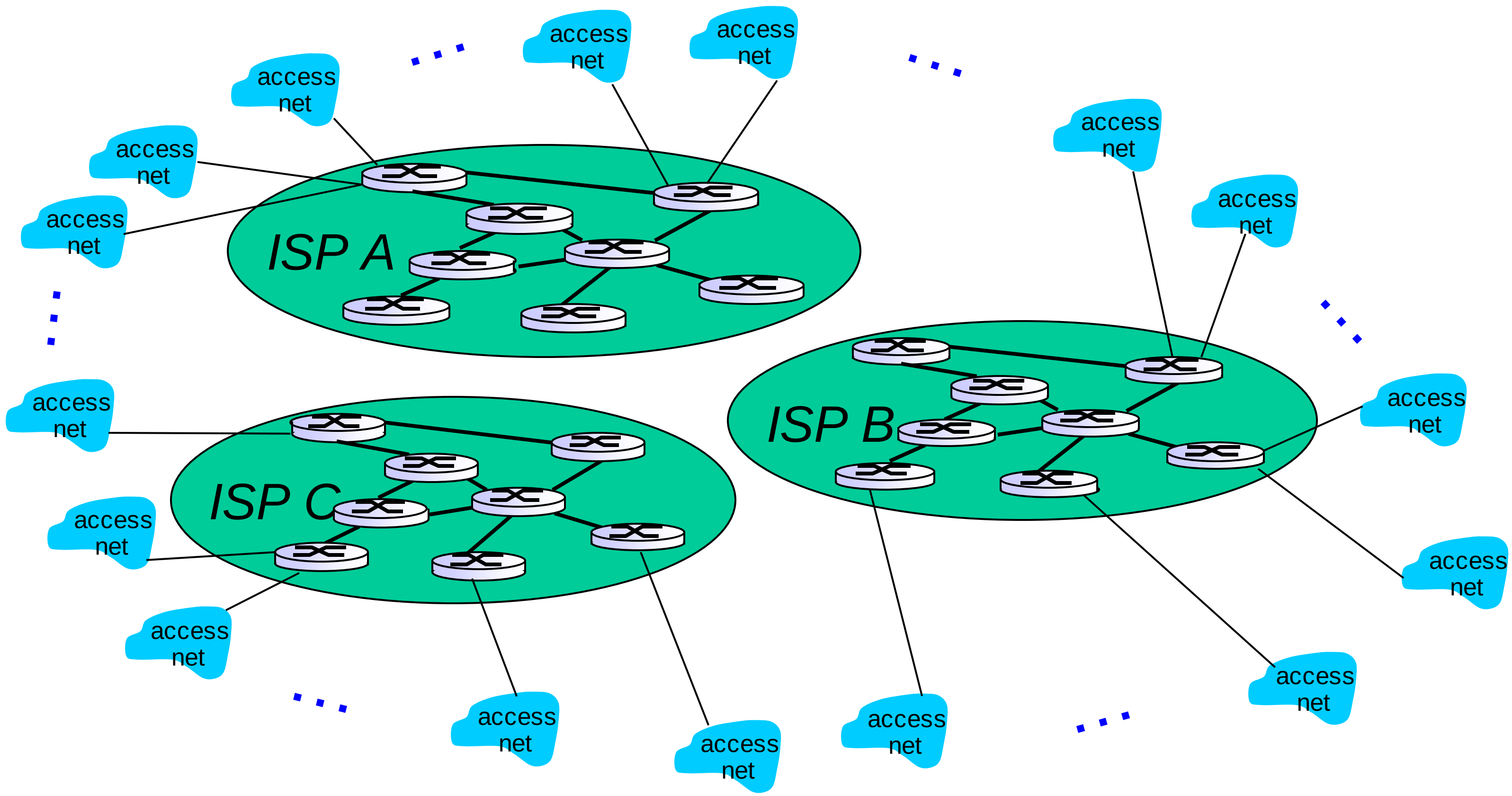
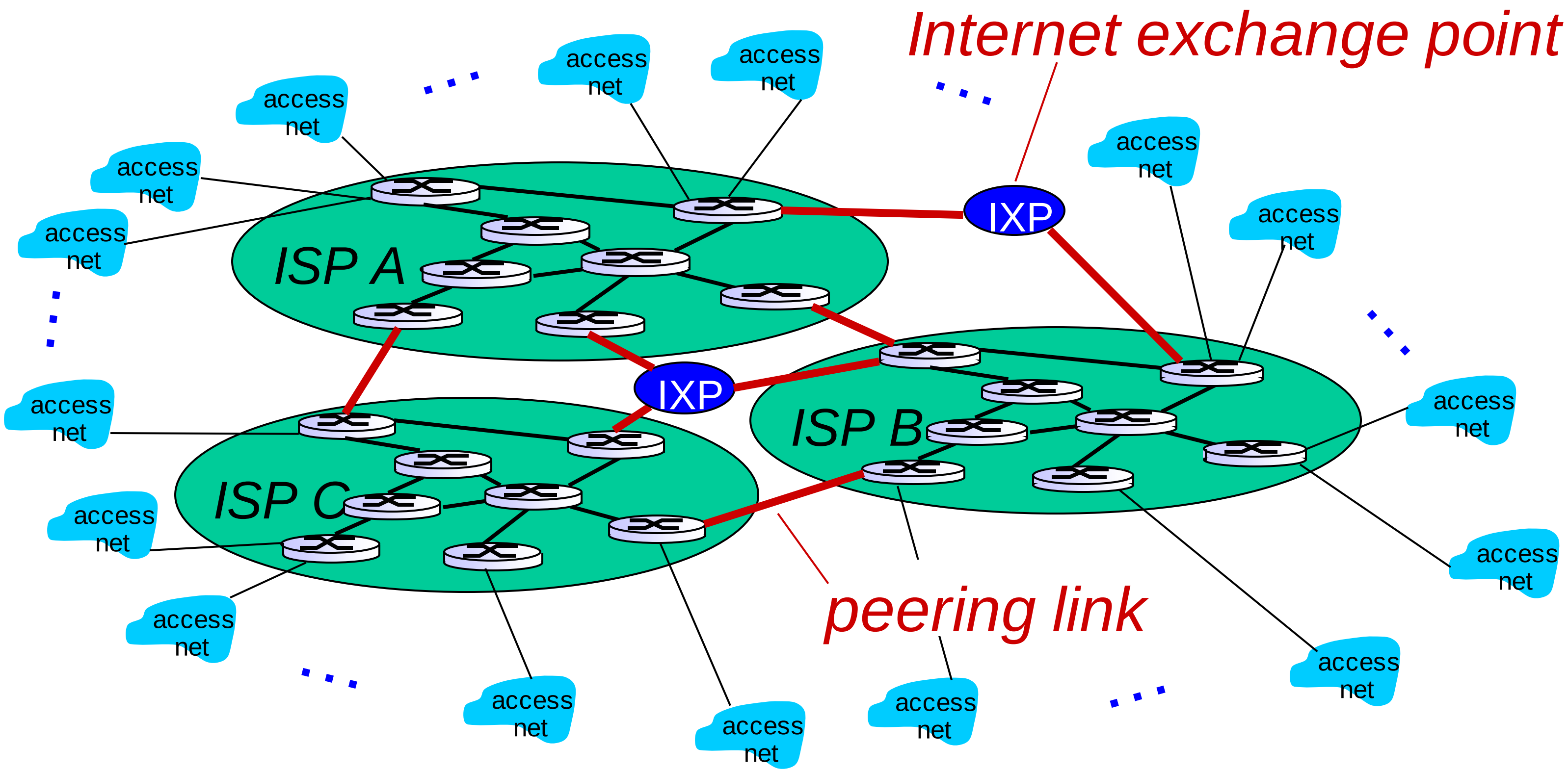
Internet structure: network of networks

- But if one global ISP is viable business, there will be competitors ….



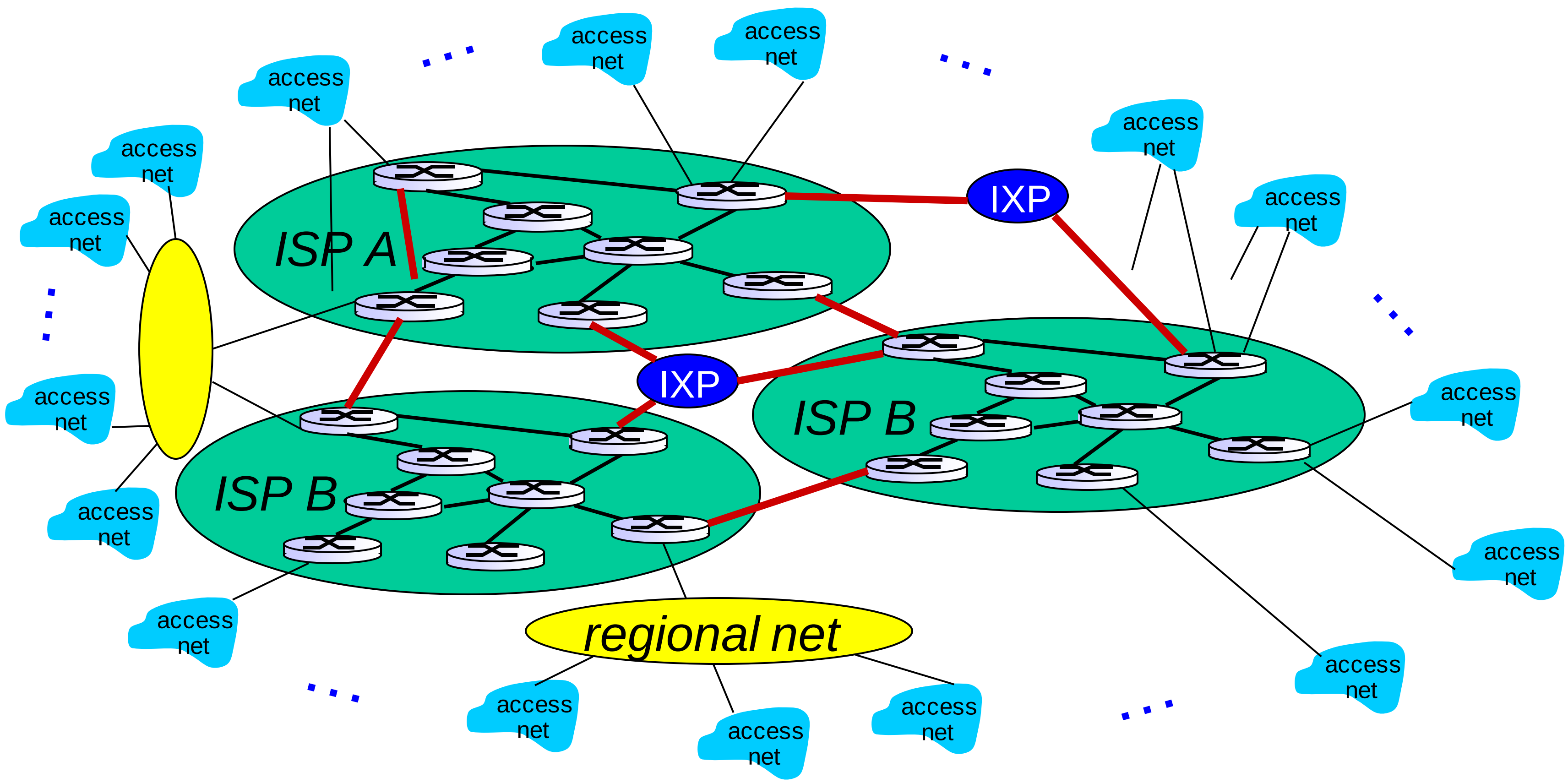
Internet structure: network of networks

- But if one global ISP is viable business, there will be competitors …. which must be interconnected



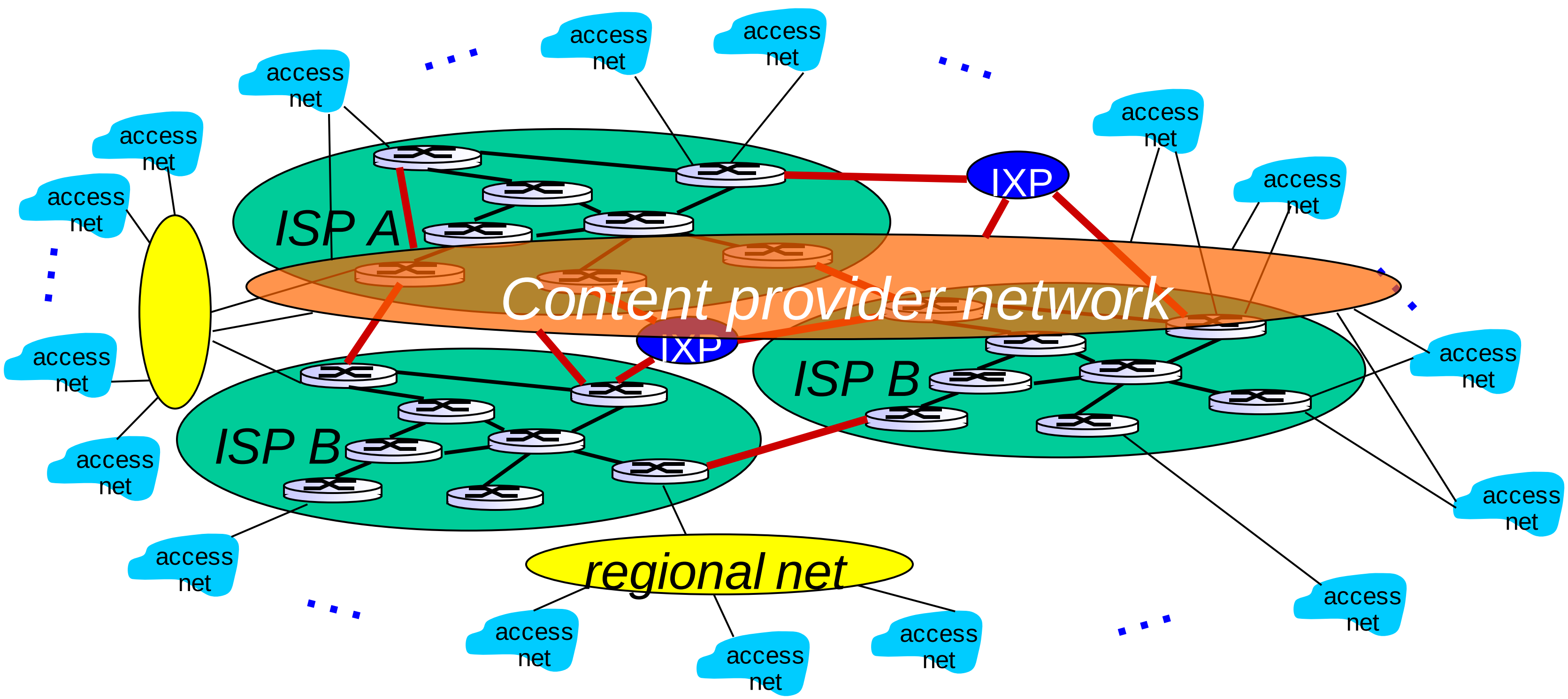
Internet structure: network of networks

- … and regional networks may arise to connect access nets to ISPS



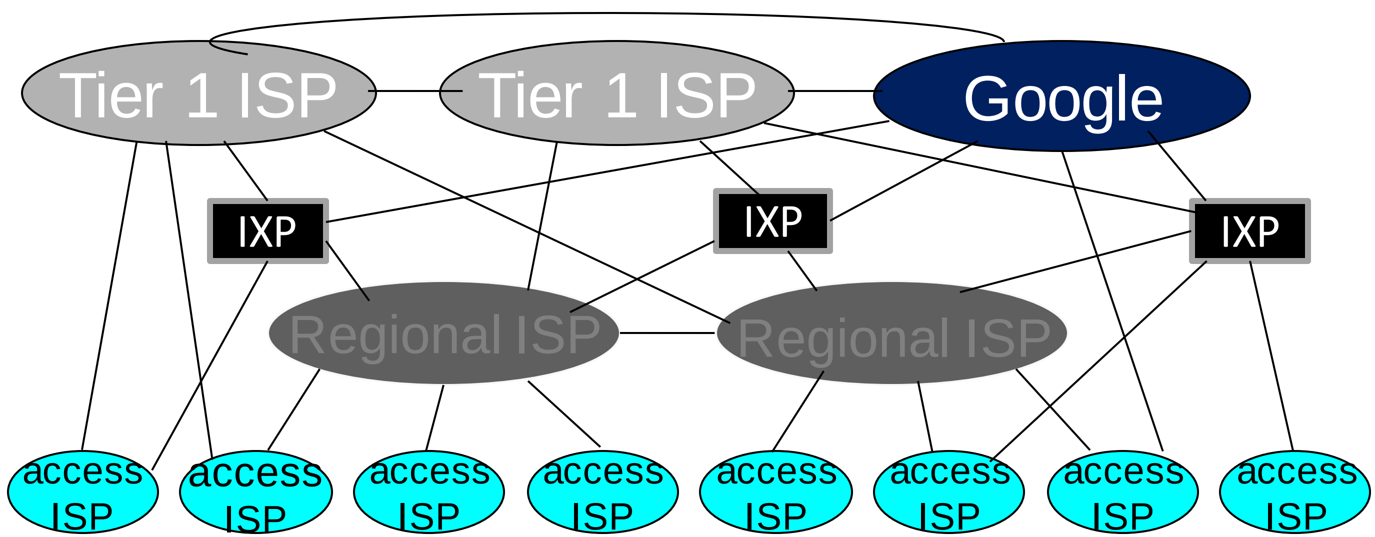
Internet structure: network of networks

- … and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users

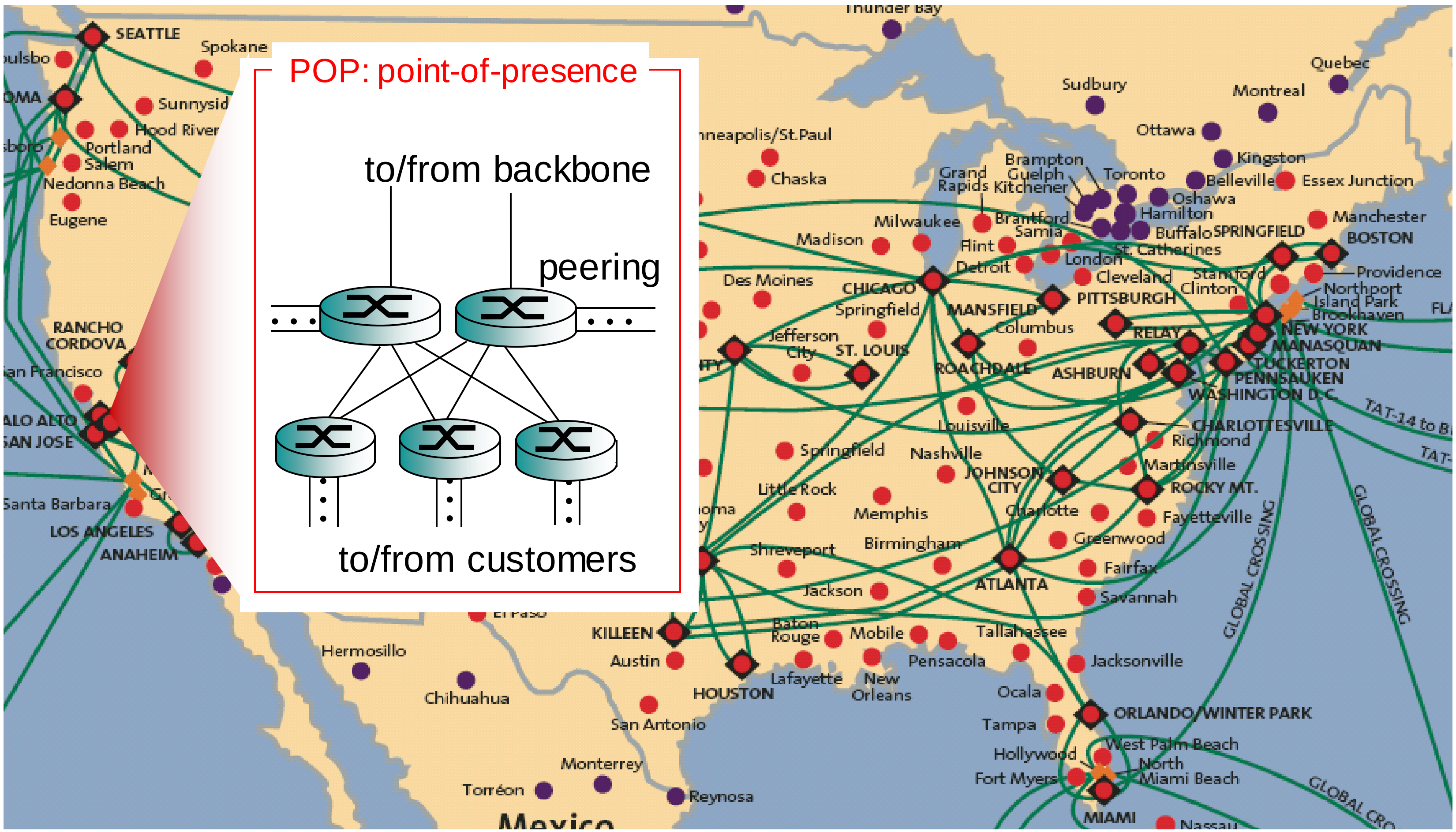


Internet structure: network of networks

- At center: small # of well-connected large networks
  - "Tier-1" commercial ISPs (e.g., Level 3, sprint, AT&T, NTT), national & international coverage
  - Content provider network (e.g., google): private network that connects it data centers to internet, often bypassing tier-1, regional ISPs



Tier-1 ISP: e.g., Sprint



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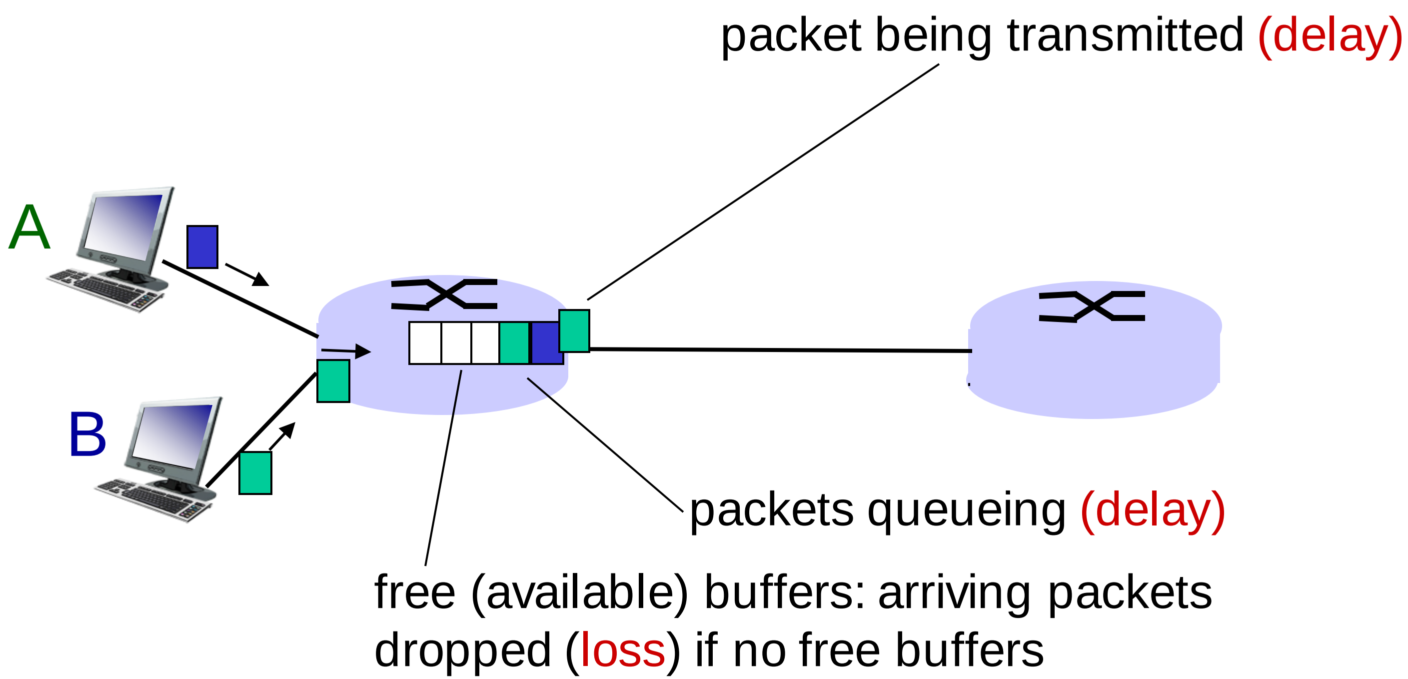
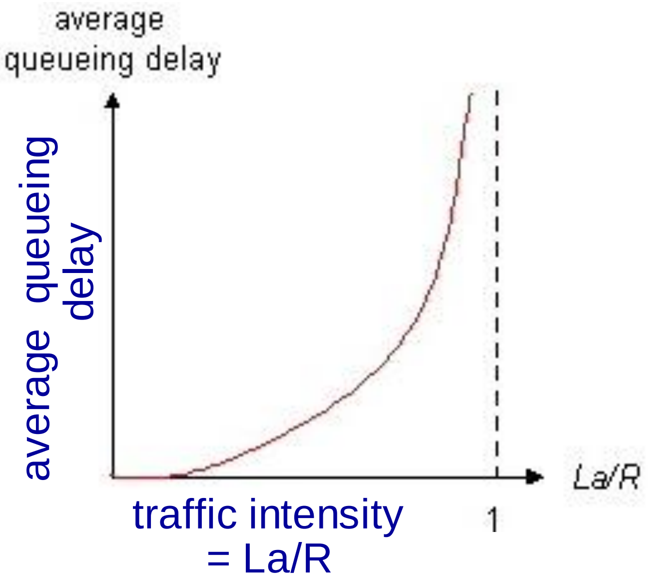
How do loss and delay occur?

- Packets queue in router buffers
  - Packet arrival rate to link (temporarily) exceeds output link capacity
  - Packets queue, wait for turn



Queueing delay (revisited)

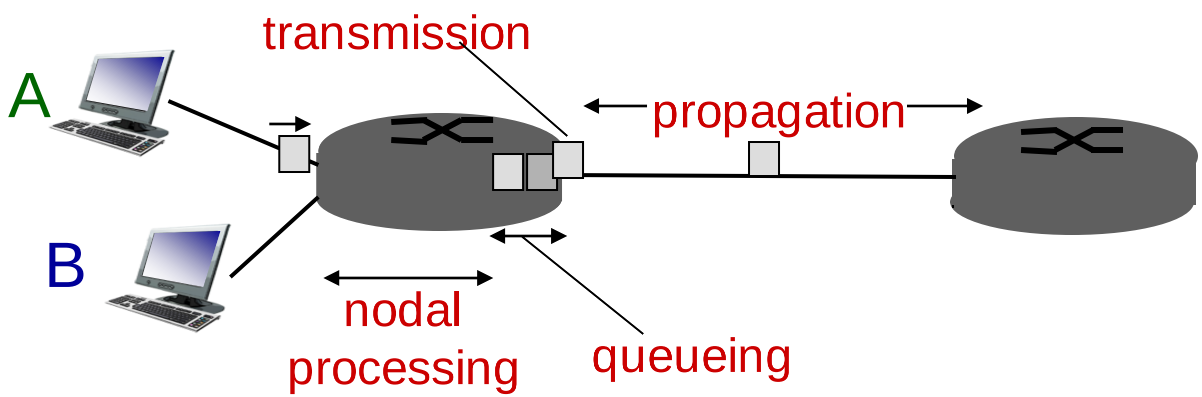
- R: link bandwidth (bps)
- L: packet length (bits)
- a: average packet arrival rate
- La/R ~ 0: avg. Queueing delay small
- La/R -> 1: avg. Queueing delay large
- La/R > 1: more “work” arriving than can be serviced, average delay infinite!



La/R -> 1

La/R ~ 0

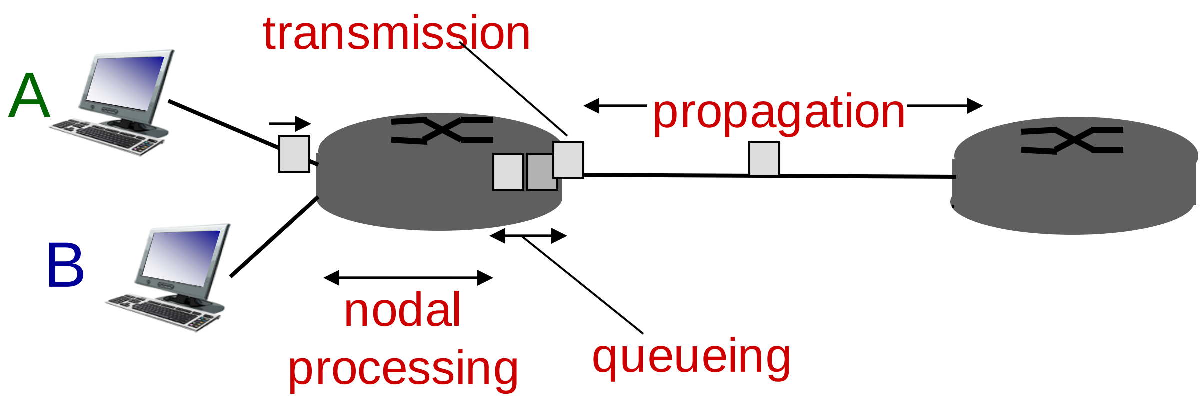
Four sources of packet delay



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

- 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

Four sources of packet delay



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

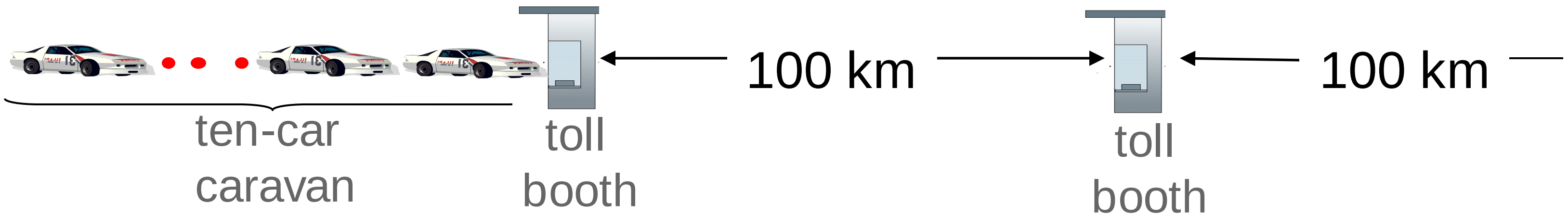
- d_{trans}: transmission delay:
  - L: packet length (bits)
  - R: link bandwidth (bps)
- d_{trans} = L/R

d_{trans} and d_{prop} *very* different

- d_{prop}: propagation delay:
  - d: length of physical link
  - s: propagation speed in medium (~2x108 m/sec)

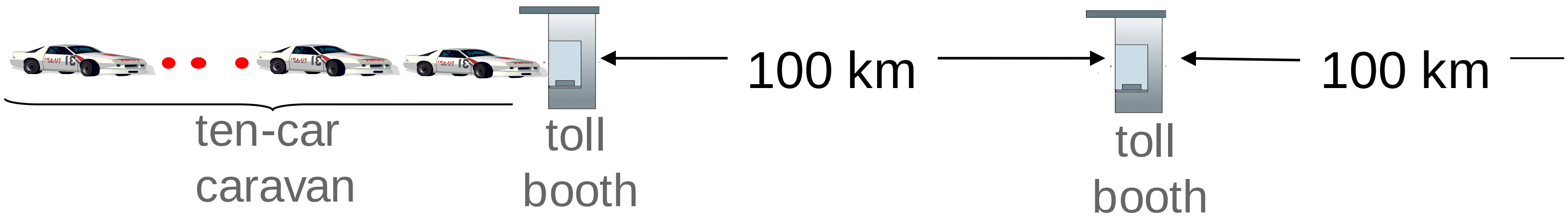
d_{prop} = *d/s*

Caravan analogy



- Cars “propagate” at 100 km/h
- Toll booth takes 12 sec to service car (bit transmission time)
- Car ~ bit; caravan ~ packet
- Q: how long until caravan is lined up before 2nd toll booth?
  - Time to “push” entire caravan through toll booth onto highway = 12*10 = 120 sec
  - Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/h)= 1 h
  - A: 2 + 60 = 62 minutes

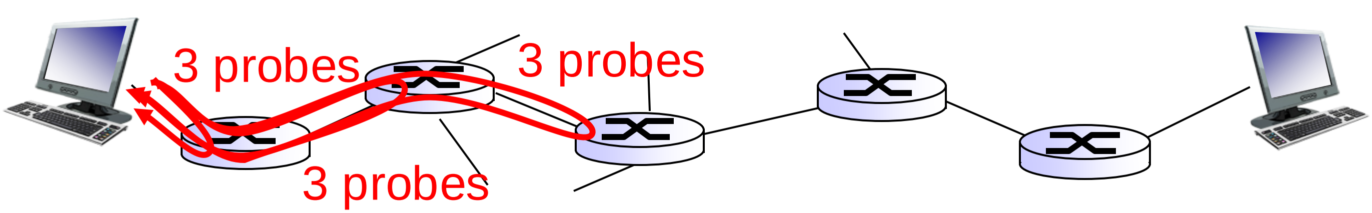
Caravan analogy



- Suppose cars now “propagate” at 1000 km/h
- And suppose toll booth now takes 1 min to service a car
- Q: how long until caravan is lined up before 2nd toll booth?
  - Time to “push” entire caravan through toll booth onto highway = 1 * 10 = 10 min
  - Time for last car to propagate from 1st to 2nd toll both:
    100km/(1000km/h) = 0.1 h = 6 min
  - A: 10 + 6 = 16 minutes
- *Q: Will cars arrive to 2nd booth before all cars serviced at first booth?*
  - *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth

"Real" Internet delays and routes

- What do "real" internet delay & loss look like?
- 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)

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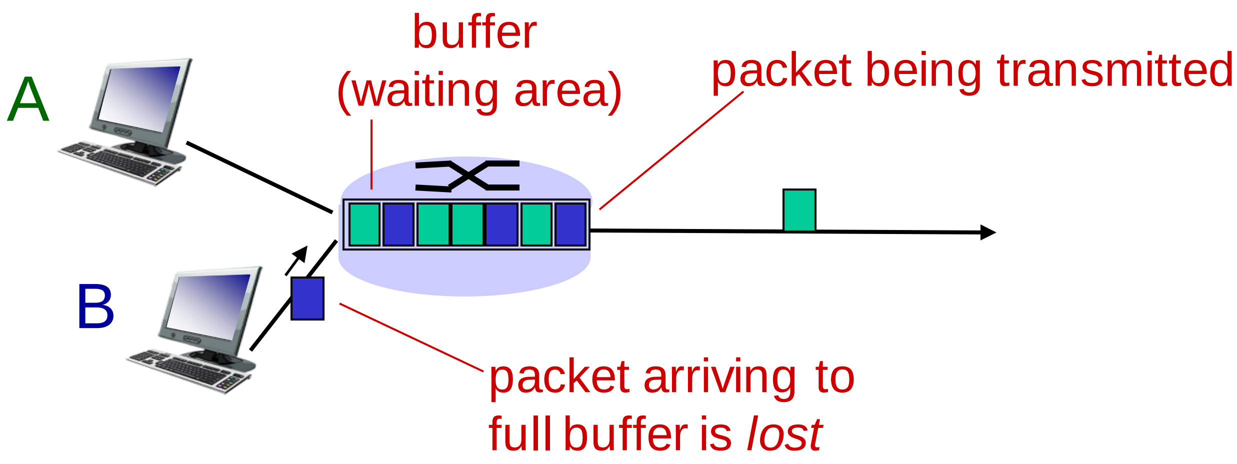
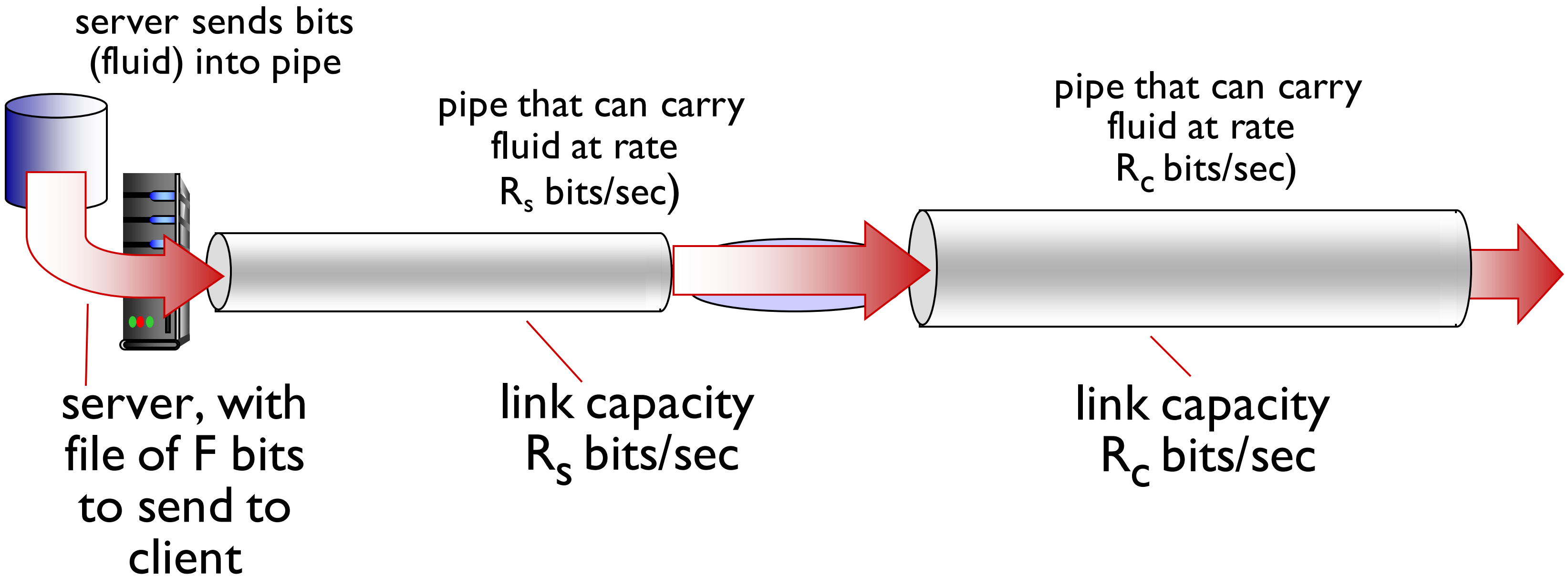
Packet loss

- 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



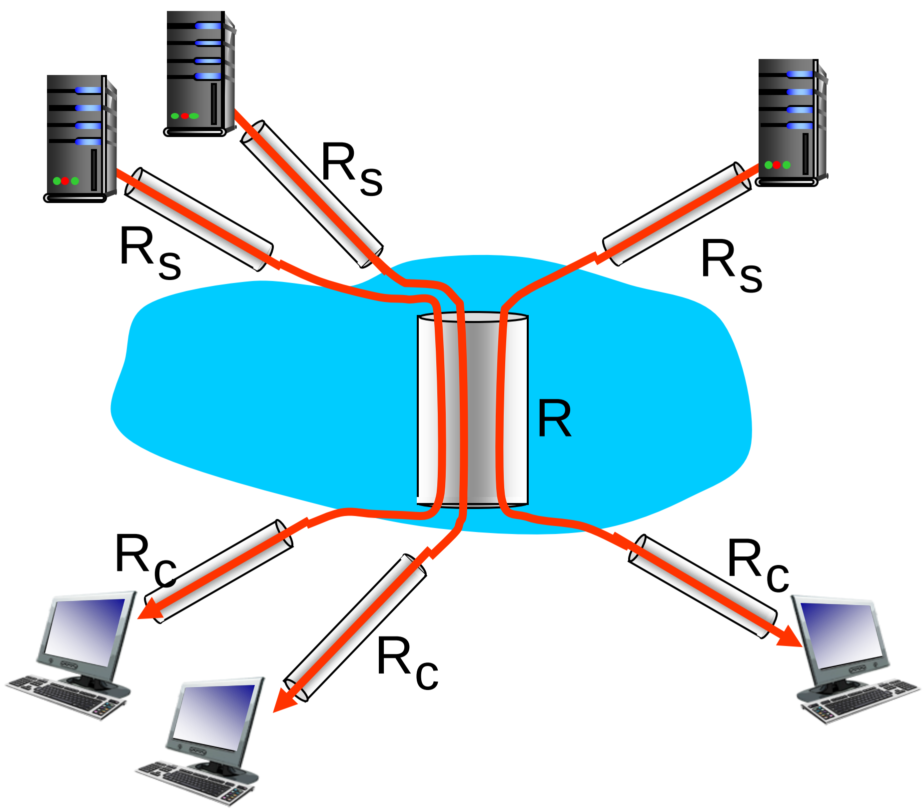
Throughput

- 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



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

Chapter 1: Roadmap

- What is the internet?
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- History

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Protocol "layers"

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

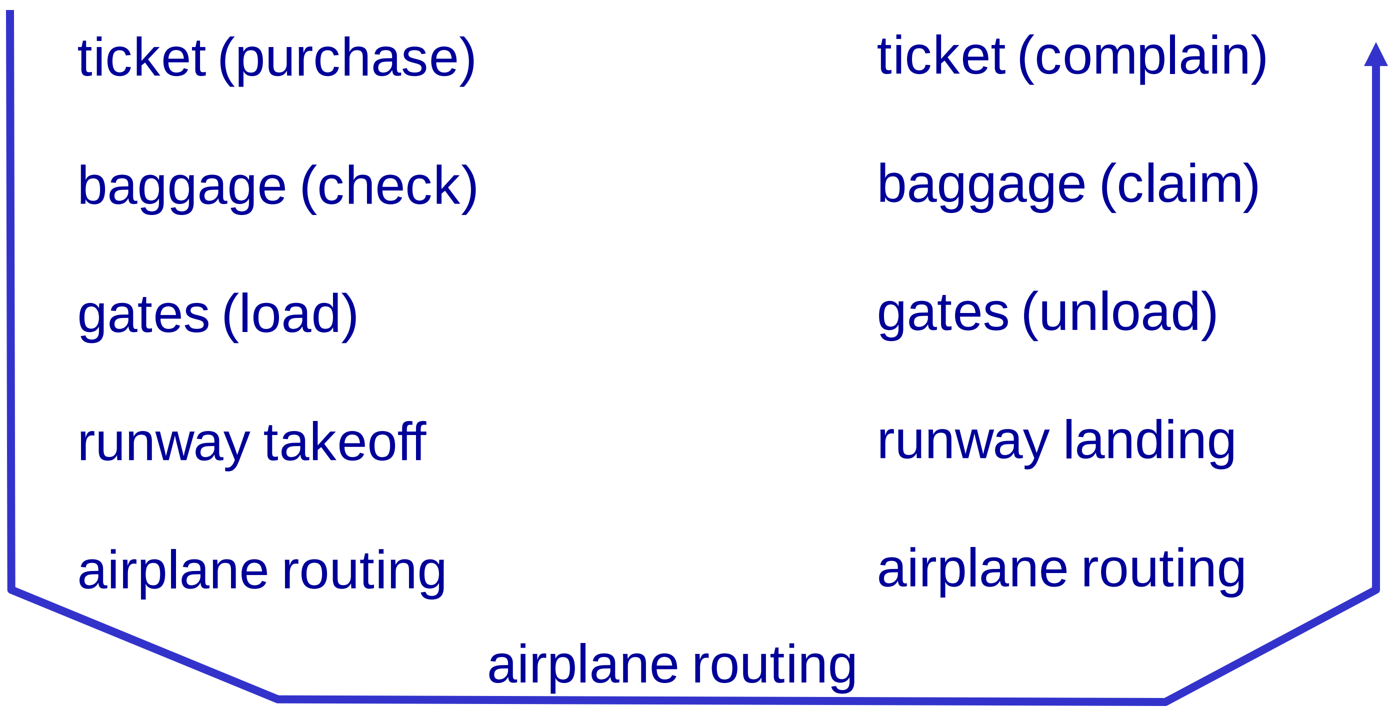
Question:

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

…. or at least our discussion of networks?

Organization of air travel

- A series of steps



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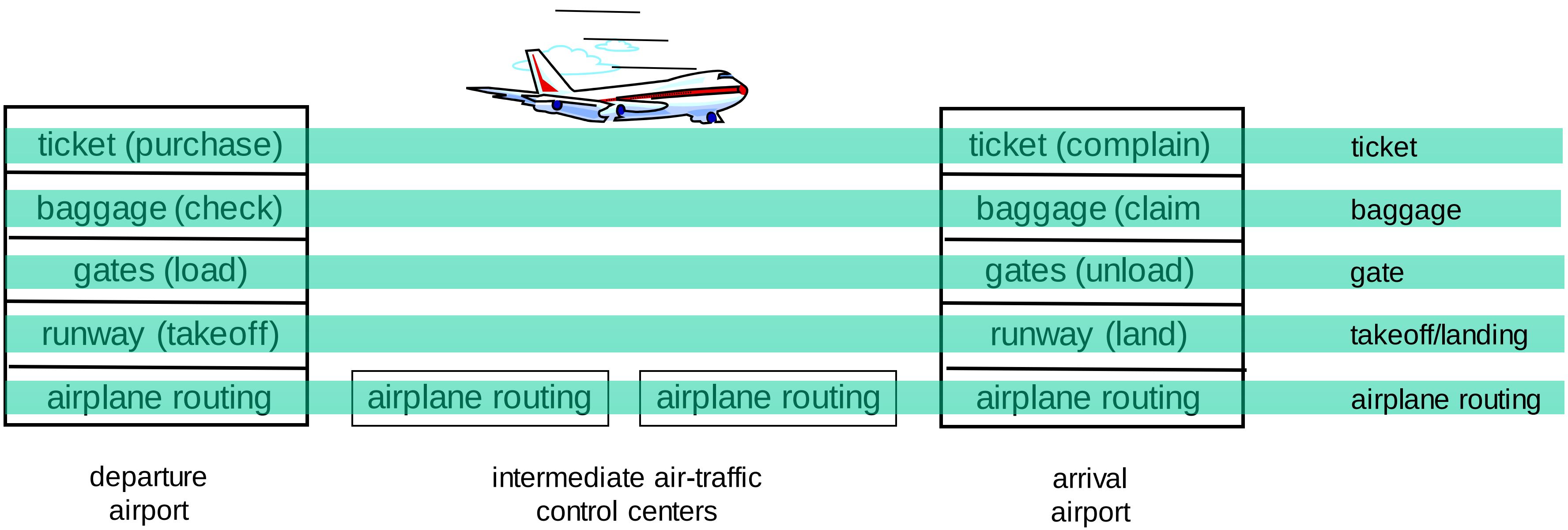
Layering of airline functionality



- Layers: each layer implements a service
  - Via its own internal-layer actions
  - Relying on services provided by layer below

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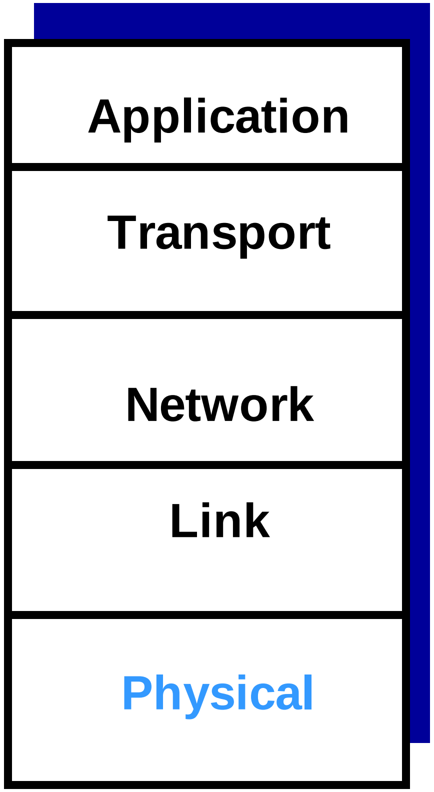
Why layering?

- 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?

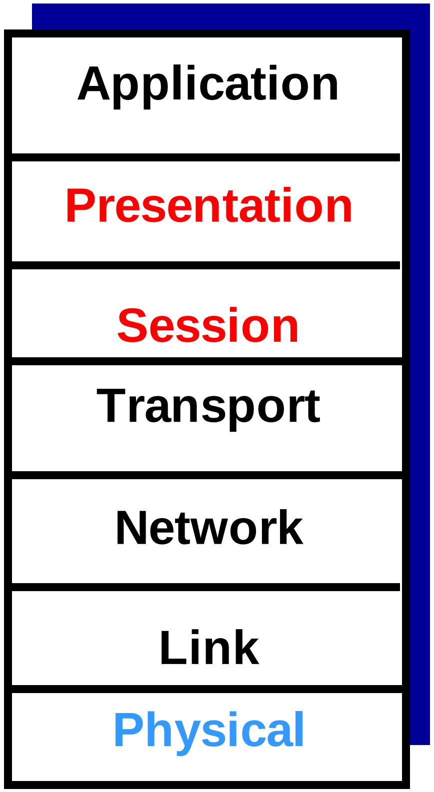
Internet protocol stack (TCP/IP protocol stack)

- Application Layer: supporting network applications
  - FTP, SMTP, HTTP
- Transport Layer : process-process data transfer
  - TCP, UDP
- Network Layer : routing of datagrams from source to destination
  - IP, routing protocols
- Data Link Layer : data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- Physical Layer : bits "on the wire"

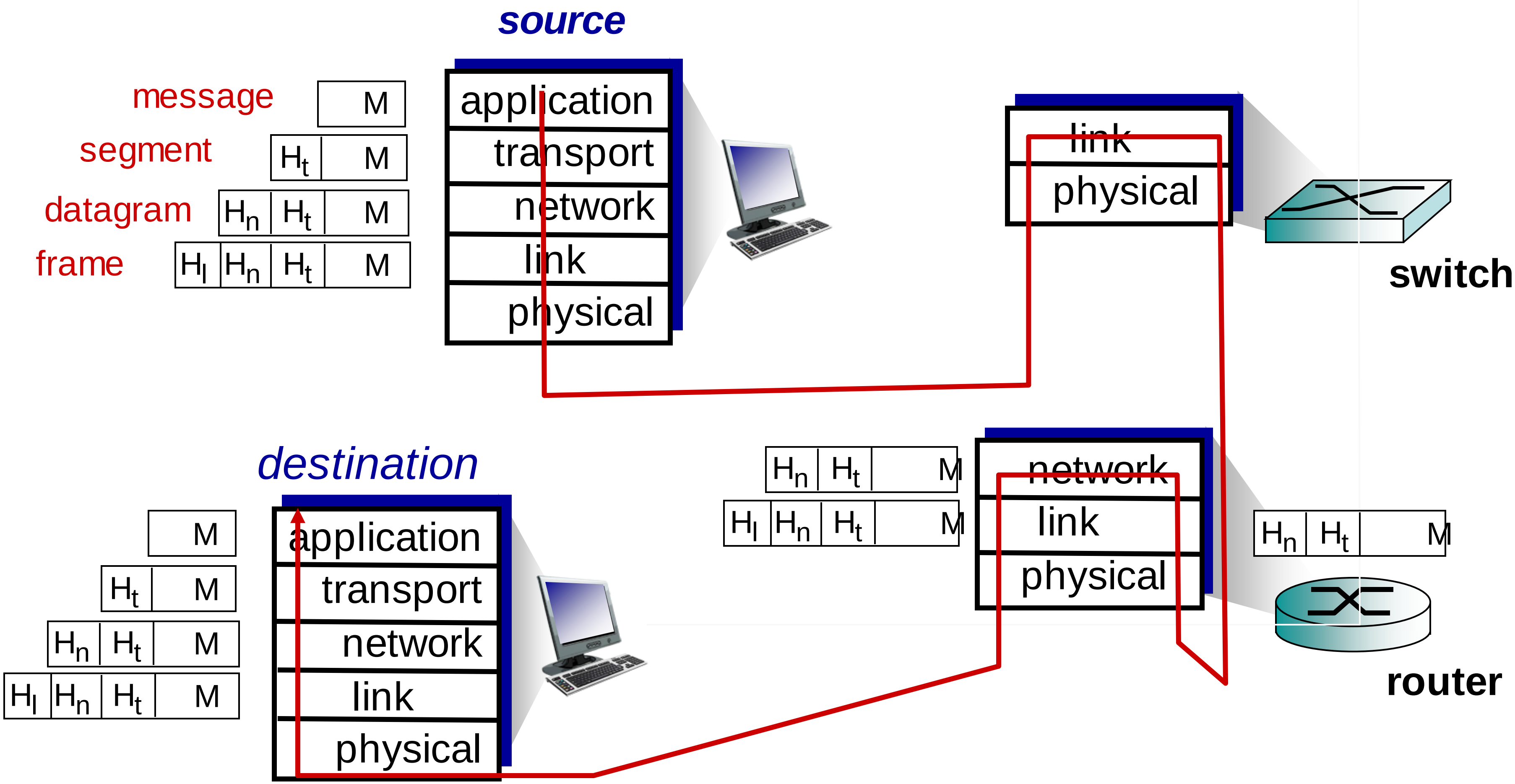


ISO/OSI reference model

- Presentation Layer: allow applications to interpret meaning of data, e.g., Encryption, compression, machine-specific conventions
- Session Layer: 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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Network security

- Field of network security:
  - How bad guys can attack computer networks
  - How we can defend networks against attacks
  - How to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - Original vision: “a group of mutually trusting users attached to a transparent network”
  - Internet protocol designers playing “catch-up”
  - Security considerations in all layers!

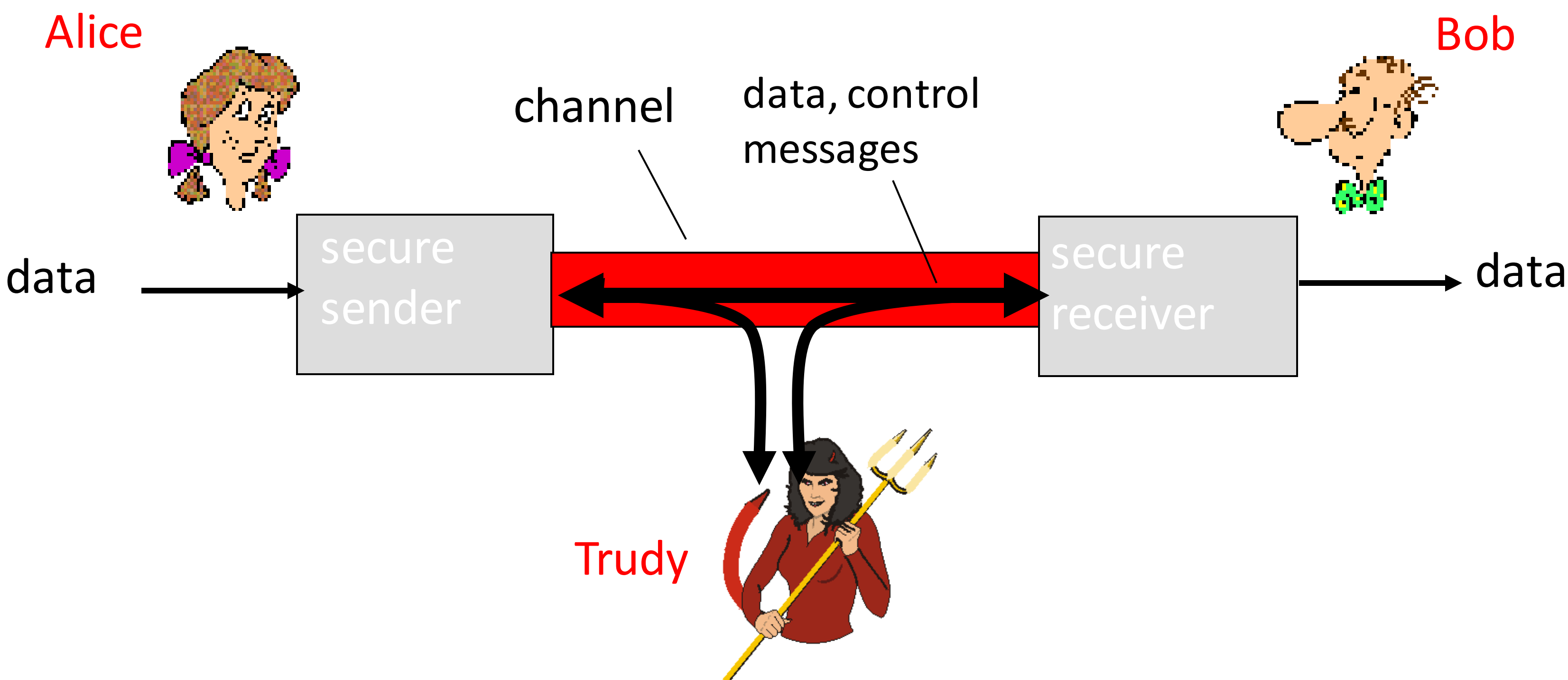
Bad guys: put malware into hosts via Internet

- Malware can get in host from:
  - Virus: self-replicating infection by receiving/executing object (e.g., E-mail attachment)
  - Worm: self-replicating infection by passively receiving object that gets itself executed
- Spyware malware can record keystrokes, web sites visited, upload info to collection site
- Infected host can be enrolled in Botnet, used for spam. DDoS attacks

What is network security?

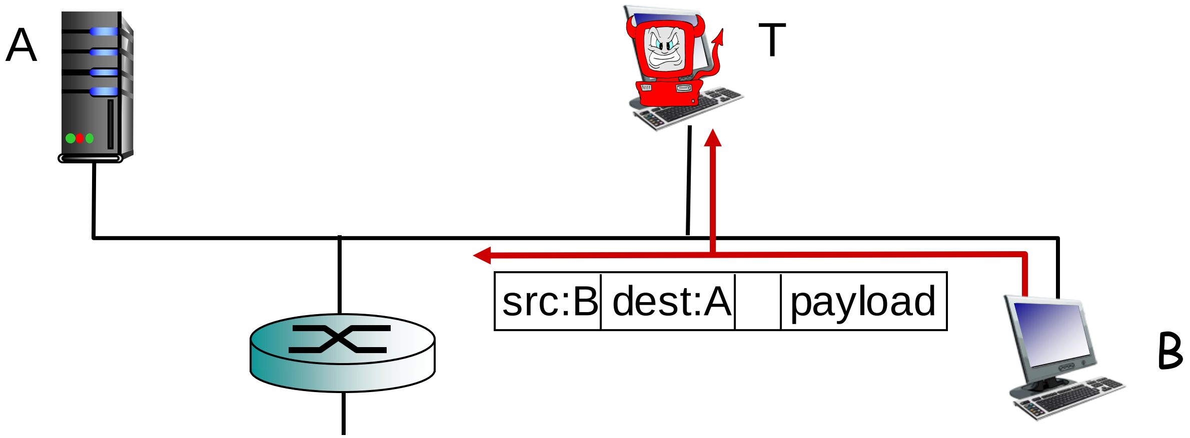
Alice Bob and Trudy

- Well-known in network security world
- Alice and Bob (lovers!) want to communicate "securely"
- Trudy (intruder) may intercept, delete, add messages



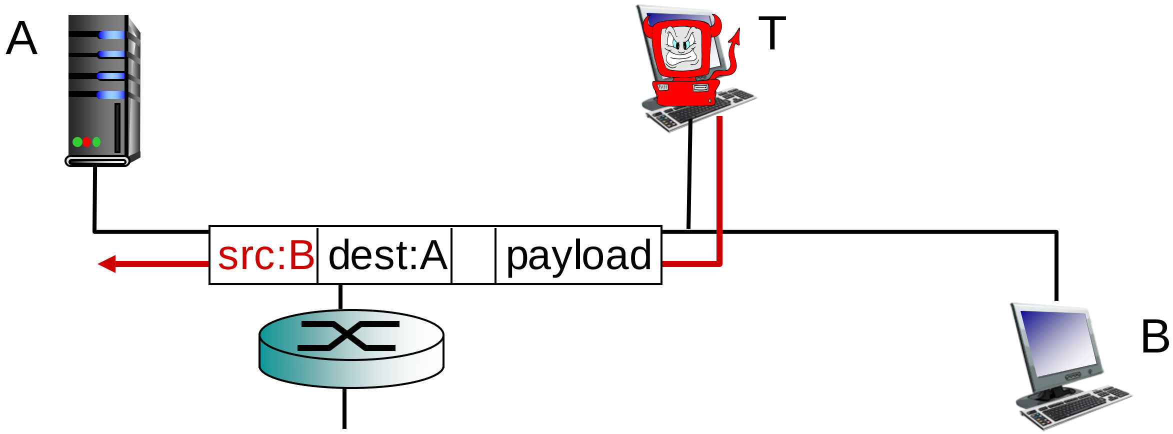
Bad guys can sniff packets

- Packet “sniffing”:
  - Broadcast media (shared ethernet, wireless)
  - Promiscuous network interface reads/records all packets (e.g., Including passwords!) Passing by



Bad guys can use fake addresses

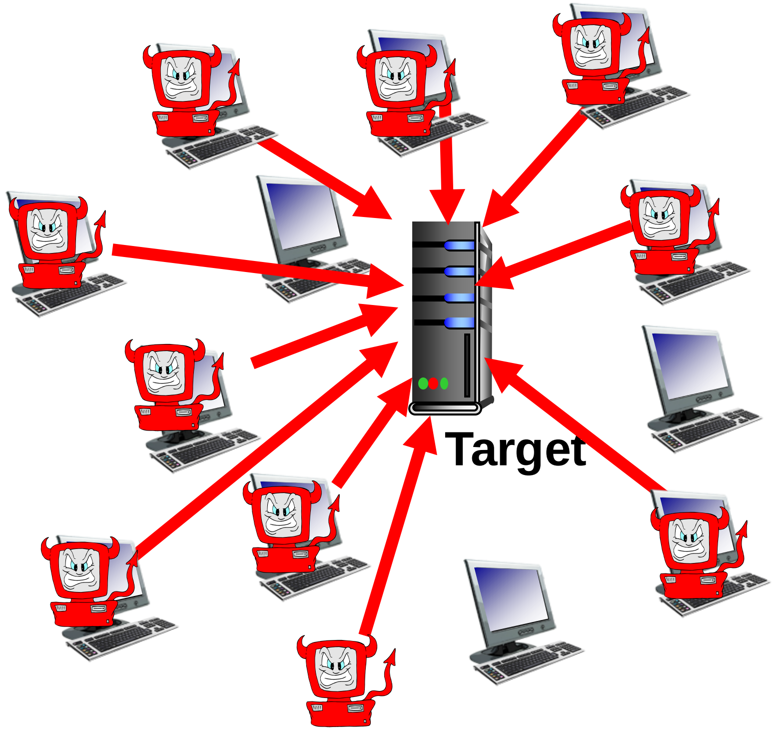
- IP spoofing
  - Send packet with false source address



Bad guys: attack server, network infrastructure

- Denial of Service (DoS):
  - Attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1) Select target
2) Break into hosts around the network (see Botnet)
3) Send packets to target from compromised hosts



What is network security?

- Confidentiality: Only sender, intended receiver should “understand” message contents
  - Sender encrypts message
  - Receiver decrypts message
- Authentication: Sender, receiver want to confirm identity of each other
- Message integrity: Sender, receiver want to ensure message not altered (in transit, or afterwards) without detection
- Access and availability: Services must be accessible and available to users

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1960-1970: Early Packet-Switching Principles

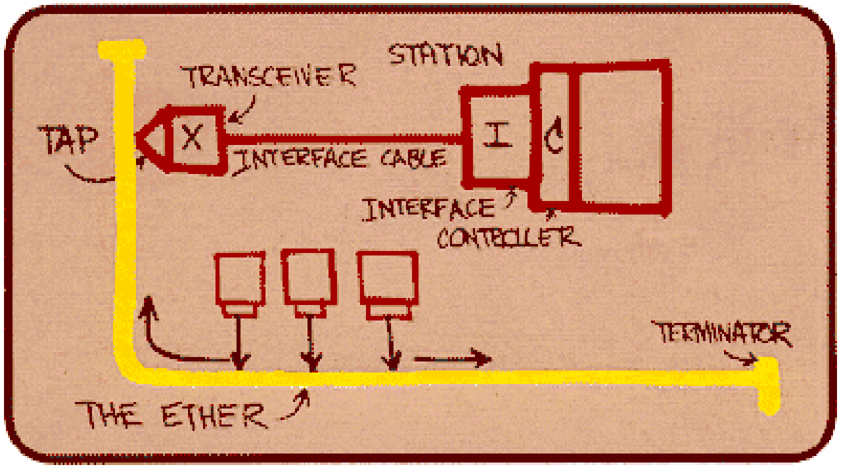
- In the 1960's: Circuit switching is the world's dominant communication technology

Source: www.superstock.com

- 1961: Leonard Kleinrock's queueing theory shows effectiveness of ***packet-switching***
- 1964: Paul Baran - packet-switching in military nets
- 1967: ARPAnet conceived by ***Advanced Research Projects Agency***
- 1969: first ARPAnet node operational
- 1972: ARPAnet has ***15 hosts***
  - Public demonstration
  - NCP (Network Control Protocol) first host-to-host protocol
  - first e-mail program (Ray Tomlinson)

1970-1980: Internetworking, New and Proprietary Nets

- 1970: ALOHAnet satellite network in Hawaii, linking universities
  - first multiple-access protocol for shared medium
- 1974: Interconnecting networks developed by Vinton Cerf and Robert Kahn for DARPA (Defense Advanced Research Projects Agency)
  - minimalism, autonomy
  - best effort service model
  - stateless routers
  - decentralized control
  - ***definition of today's Internet architecture***
- 1976: Robert M. Metcalfe and David Boggs develop ***Ethernet*** at Xerox PARC

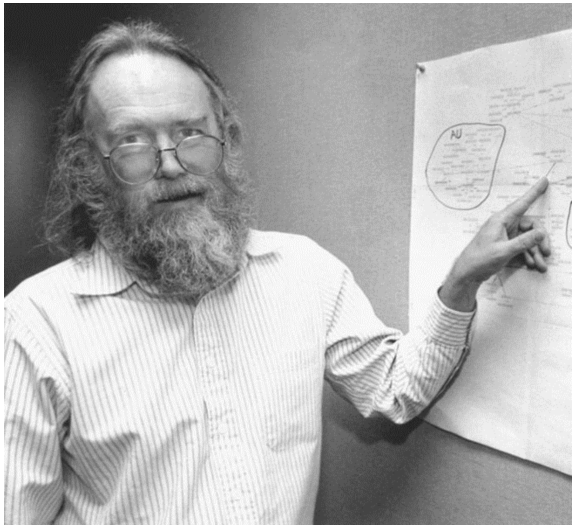


Metcalfe's original conception of the Ethernet

- 1979: ARPAnet has ***200 hosts***

1980-1990: New Protocols – Proliferation of Networks

- New national networks emerged
  - CSNET, BITnet, NSFnet, Minitel
- 1981: IPv4 standard (ed.: Jon Postel)
- 1982: Jon Postel proposes SMTP e-mail protocol
- ARPAnet community develops many pieces of today's Internet
  - 1983: deployment of TCP/IP – all hosts had to switch from NCP to TCP/IP at one day
  - 1983: Domain Name System (DNS) defined for name-to-IP-address translation



Jon Postel in 1994

He edited or co-authored more than 200 RFC's, including IP, ICMP and TCP (basic protocols of the Internet).

- 1985: File Transfer Protocol (FTP) by Jon Postel and Joyce Reynolds
- Late 1980's: ***160.000 hosts*** connected to confederation of networks

1990-1995: Commercialization and the World Wide Web

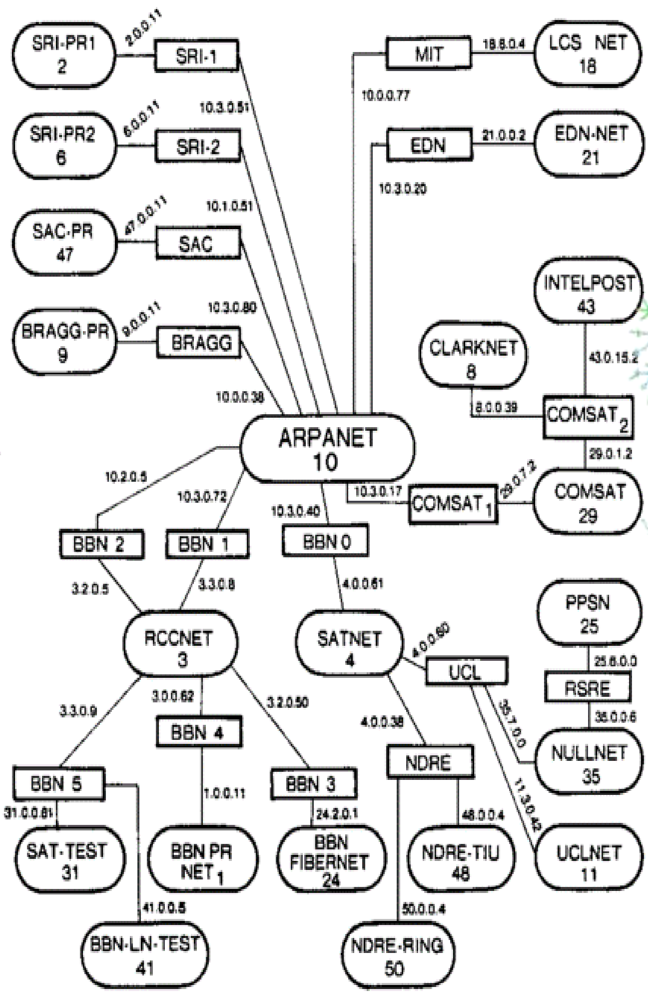
- Early 1990's: The Internet evolves
  - ARPAnet decommissioned
  - NSFnet serves as backbone
  - NSFnet allows commercial use
- 1991: Tim Berners-Lee creates ***World Wide Web (WWW)*** at CERN, Switzerland
  - based on hypertext [Bush 1945, Nelson 1960]
  - 4 main components: HTML, HTTP, Web-server, browser
- 1993: ***200 Web servers*** in operation
  - commercialization of the Web
- 1994: First GUI browsers developed
  - Mosaic (Marc Andreessen), became Netscape later on
- 1995: NSFnet decommissioned
  - backbone now provided by commercial Internet Service Providers (ISPs)
- 1995: Internet has ***~5 mio hosts***

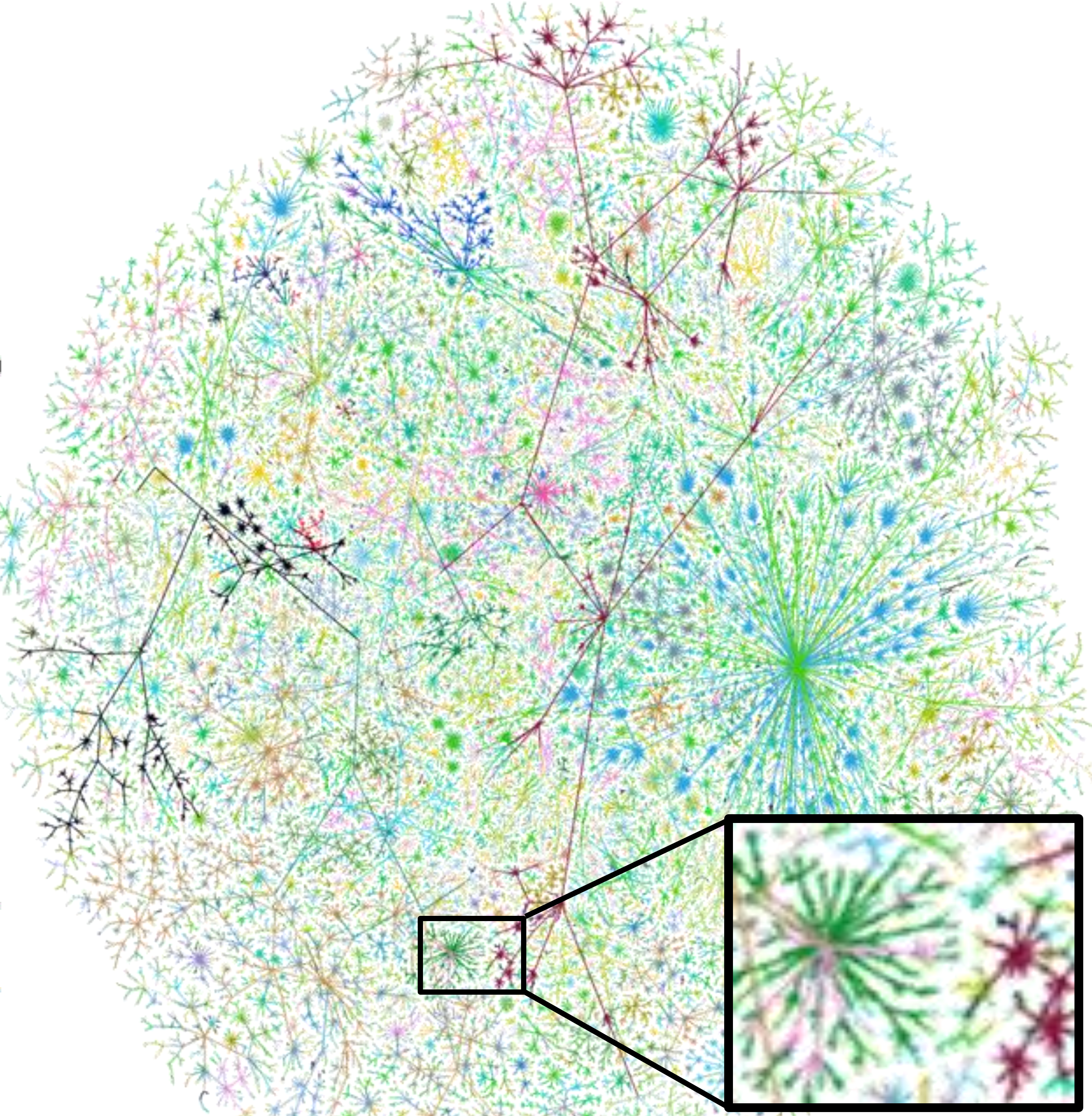
1995-1999: Browser War and Killer-Applications

- 1995: Wiki
  - WikiWikiWeb on c2.com
  - websites become editable
- 1996: Microsoft's Internet Explorer
  - starts browser-war: Netscape Navigator vs. Microsoft Explorer
  - won by Microsoft around 1998
- 1998: ICQ, instant messaging pioneer
- 1998: First IPv6 RFC (RFC 2460)
  - qualitative progress
  - longer IP-Addresses (128 bit)
  - security in the network layer
  - quality of service
- 1998: Google Search
  - popular because of its simplicity

- 1999: Blog (weblog)
  - Open Diary, LiveJournal, blogger.com, …
- 1999: Napster (Shawn Fanning)
  - peer-to-peer file-sharing pioneer

Maps of the Internet: 1982 and 1999





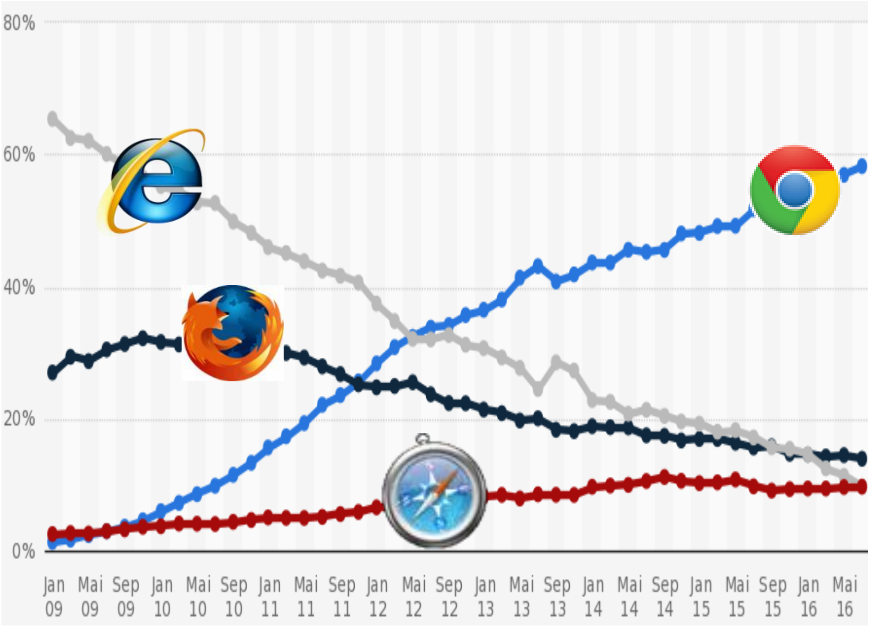
Source: Jon Postel, Feb. 1982
http://en.wikipedia.org

Source: Internet Mapping Project, June 1999 (~56 mio hosts)
http://www.cheswick.com

2000 - today: Web 2.0 and Social Networks

- 2000: The dot.com bubble bursts
  - loss of ***$5 trillion*** in the market value of companies (until 2002)
- 2001: Wikipedia
- 2003: Skype Voice-over-IP
- 2004: Facebook
- 2004: Release of Mozilla Firefox 1.0
  - based on Netscape Navigator
  - second browser war begins

Second browser war



Source: StatCounter

- 2005: Internet has ***~350 mio hosts***

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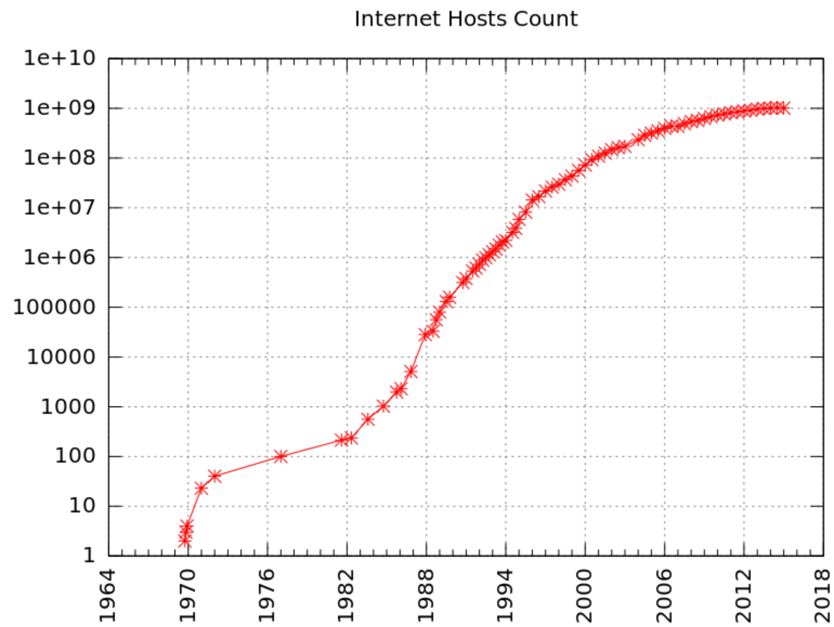
2000 - today: Web 2.0 and Social Networks

- 2006: WikiLeaks
  - Publishing of confidential data
- 2006: Twitter
- 2007: Apple iPhone
  - smart phones enter the Internet
  - the Internet goes mobile
- 2008: Mobile Internet takes over
  - more mobile broadband subscriptions than fixed broadband subscriptions (Source: Source: ITU World Telecommunication/ICT Indicators Database)
- 2009: Whatsapp



- Today: The Internet has
  - ***~ 1.000.000.000*** hosts

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Summary

- covered a “ton” of material!
  - Internet overview
  - what’s a protocol?
  - network edge, core, access network
    - packet-switching versus circuit-switching
    - Internet structure
  - performance: loss, delay, throughput
  - layering, service models
  - security
  - History

- you now have:
  - context, overview, “feel” of networking
  - more depth, detail to follow!