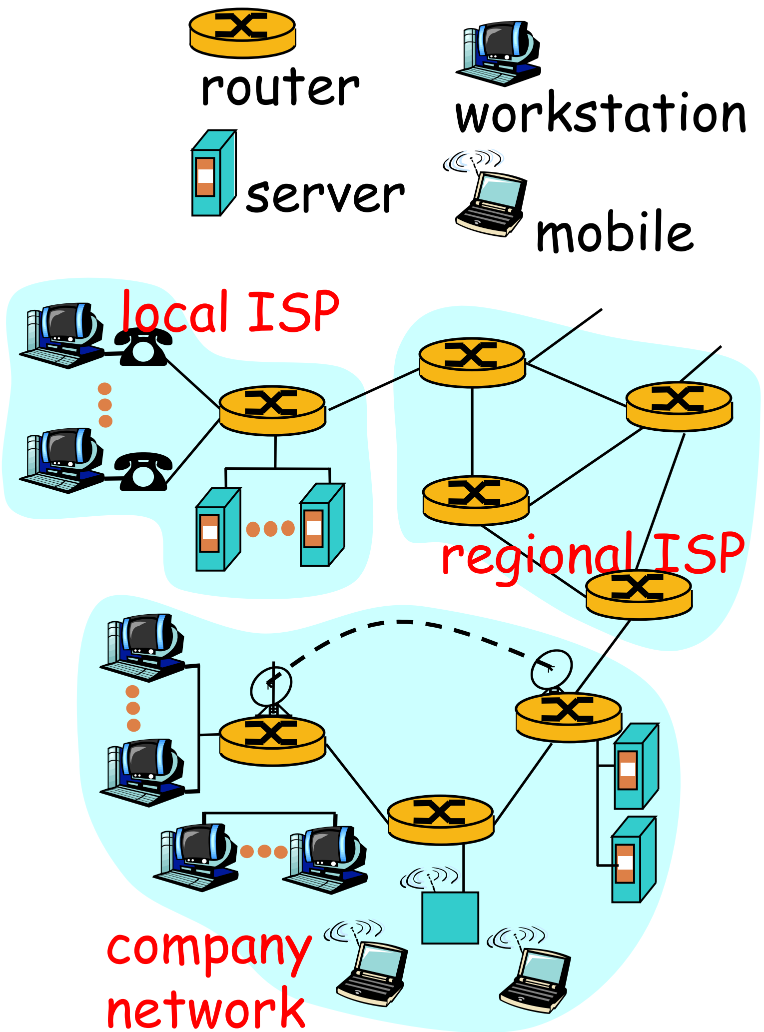
TOPIC 2 COMPUTER NETWORK

What’s the Internet: “nuts and bolts” view

- millions of connected computing devices.
  - *hosts = end systems*
- running *network apps*
- End Systems are connected by:
  - *communication links*
    - fiber, copper, radio, satellite
    - transmission rate = ***bandwidth***
  - *Routers and switches:*
    - Takes packets arriving on one of incoming link and forwards it on one of its outgoing link
    - Route, Path.

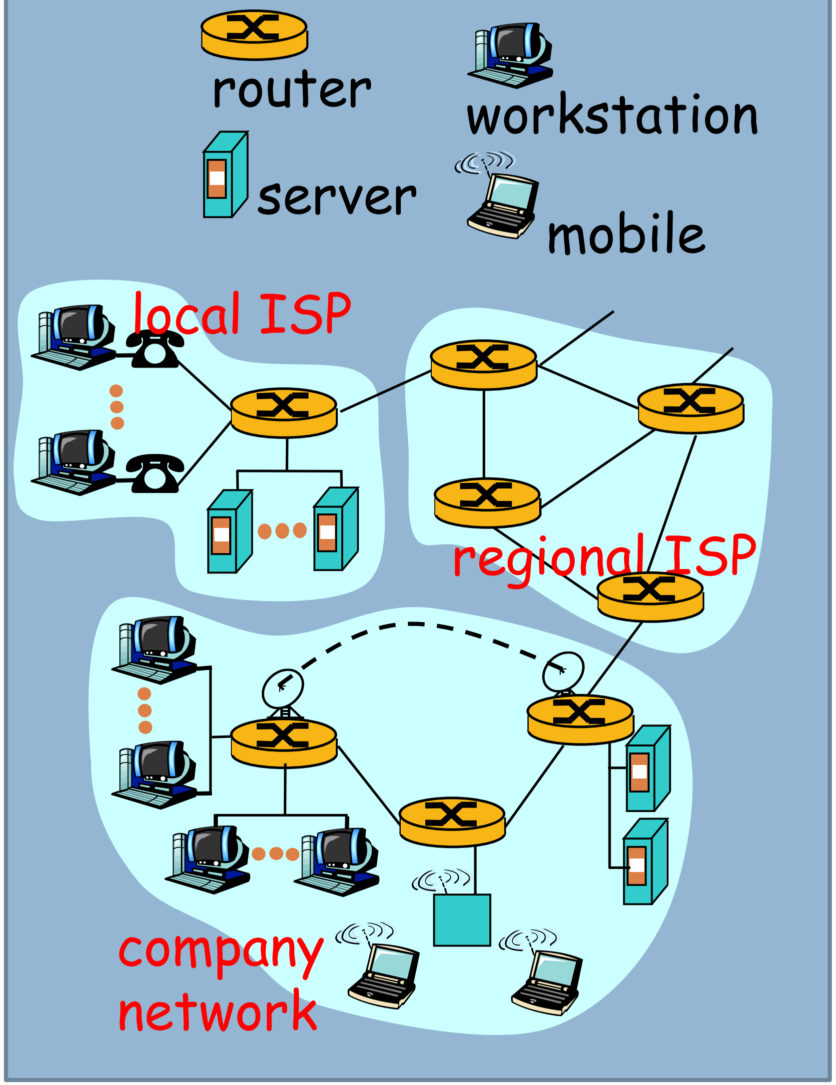


What's the Internet: "nuts and bolts" view

Software Side

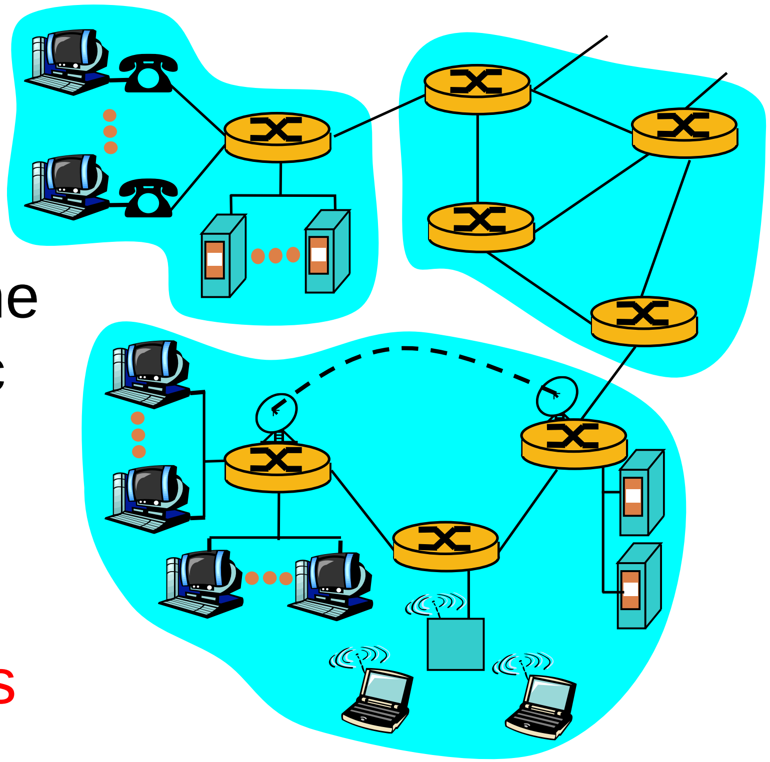
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
  - Internet standards
    - RFC: Request for comments
    - IETF: Internet Engineering Task Force

Hardware Side



What's the Internet: a service view

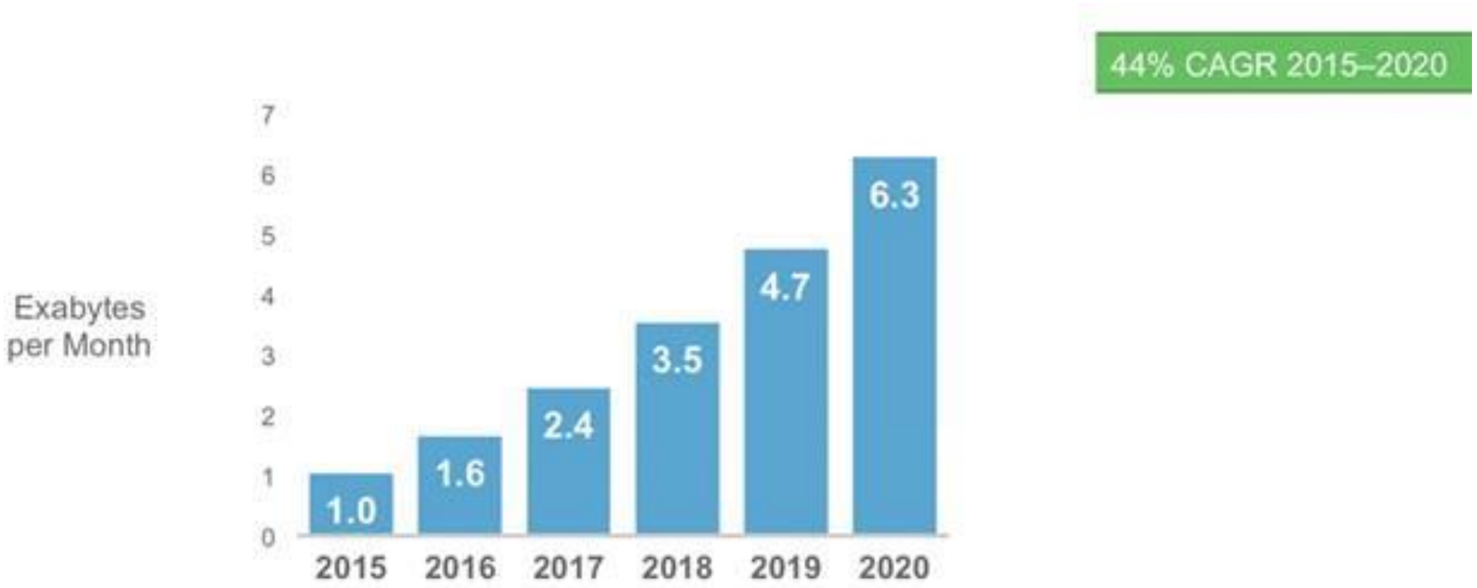
- communication *infrastructure* enables distributed applications:
  - Web, email, games, e-commerce, file sharing
- How does an application instruct the Internet to deliver data to a specific destination?
  - Use Application Programming Interface(API)
- What are communication services provided to apps?
  - They can be one of the following services
    - Connectionless unreliable
    - connection-oriented reliable



The State of the Internet

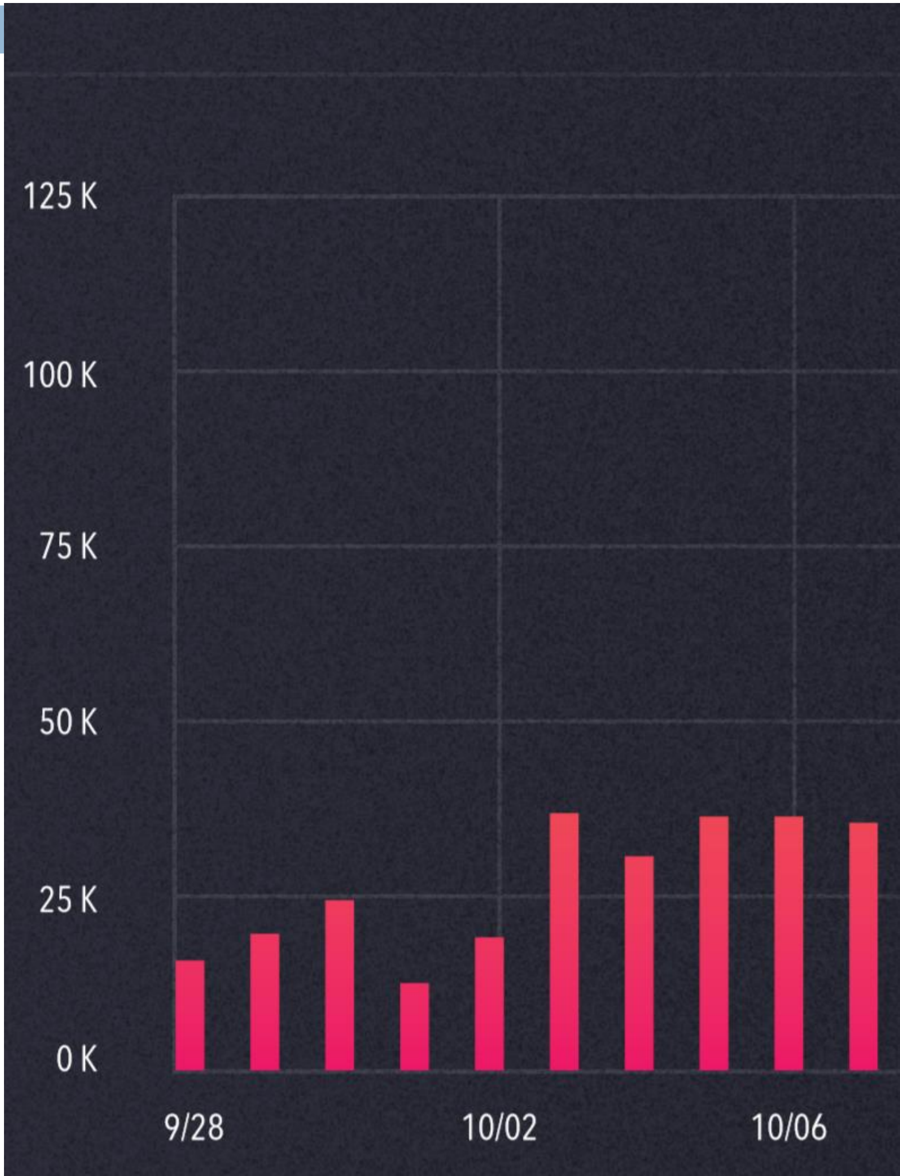
1-5

- In 2005, AT&T estimate the Internet traffic enters its network at a rate of 250Gbps
- In 2006, PriMetrica estimates 5Tbps of international capacity was used by public carrier



State of Internet 2018

- Increased number of malicious 0 day domains
  - 60% increase!



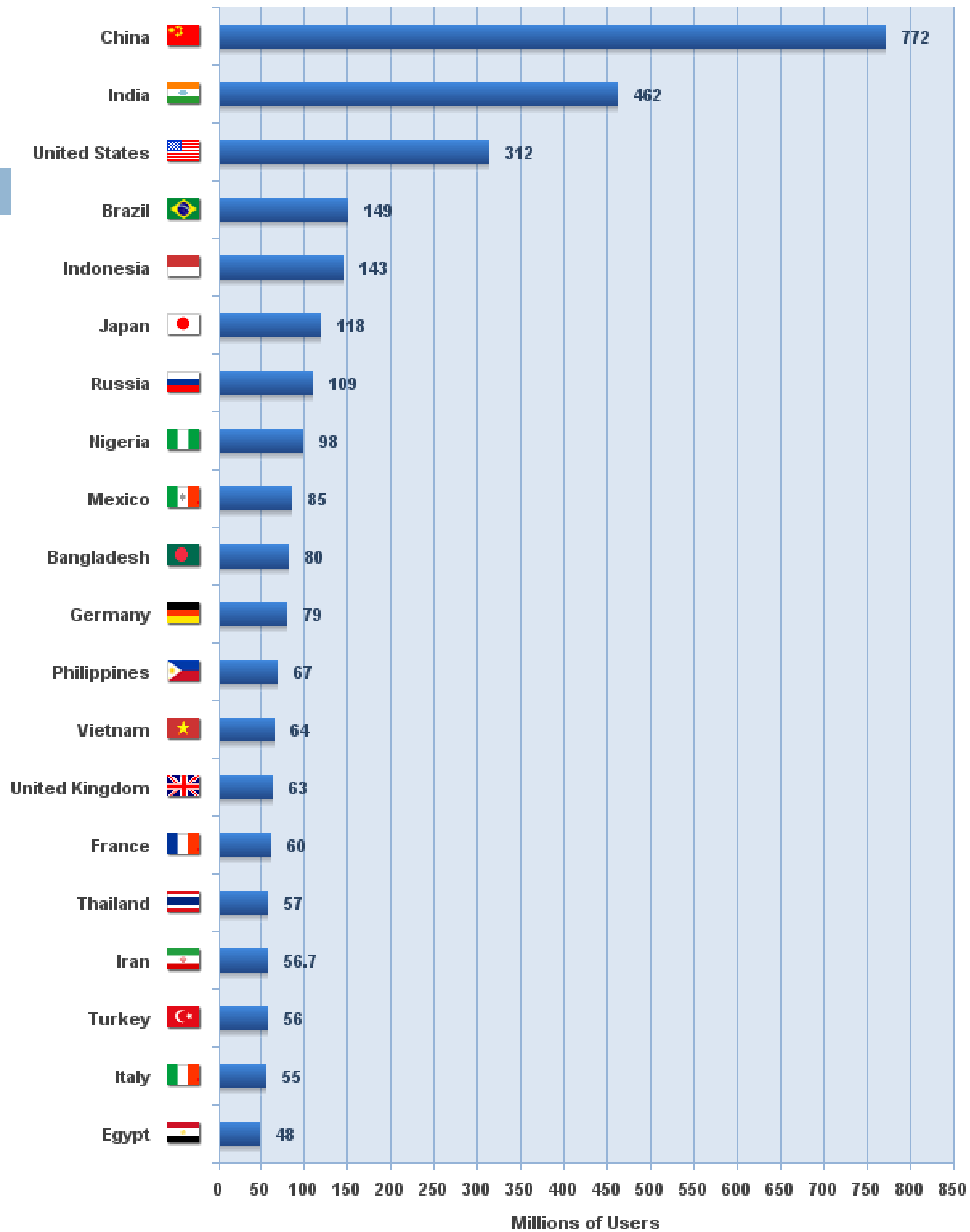
Is It a Coincidence That the Internet's Birthday and National Cat Day Are the Same Day?

1-7

Adam Clark Estes

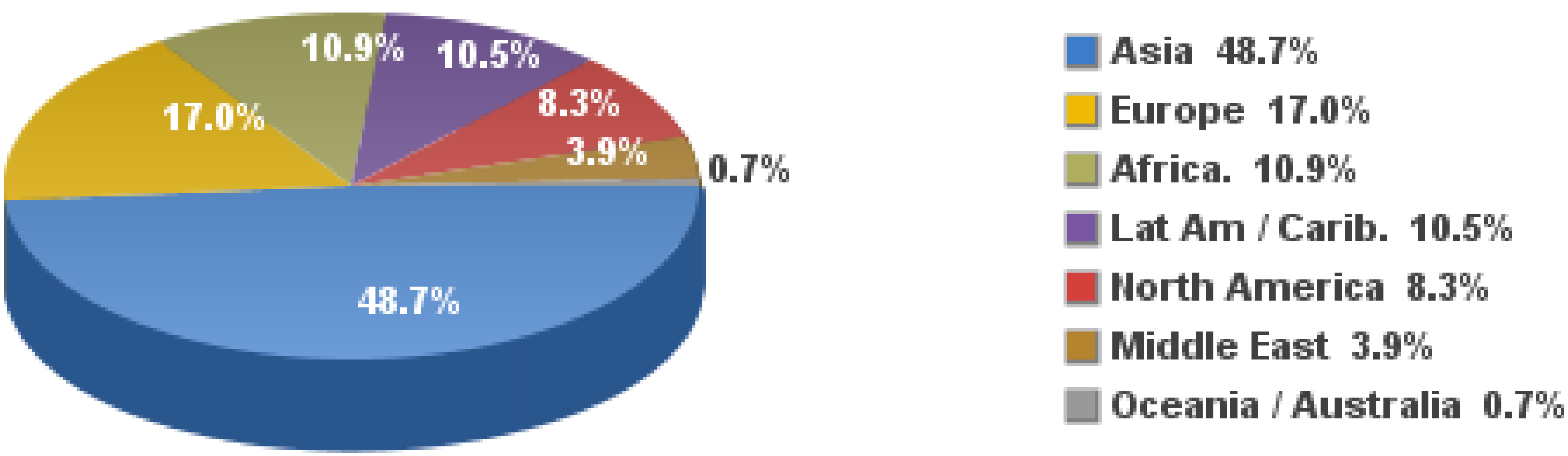
Filed to: HAPPY BIRTHDAY TO YOU 10/29/15 6:00pm

TOP 20 INTERNET COUNTRIES - 2018
With the Highest Number of Internet Users



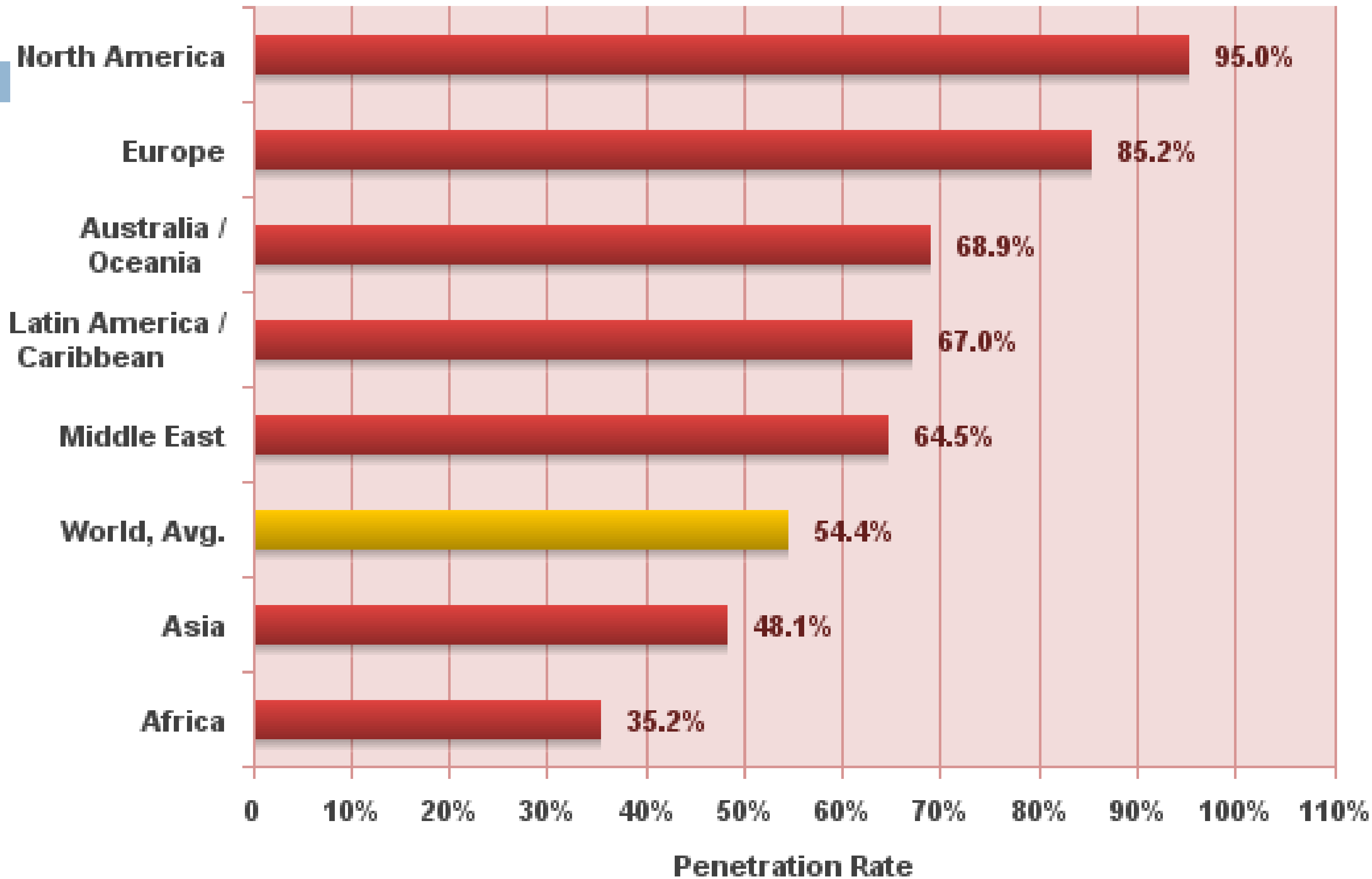
Source: Internet World Stats - www.internetworldstats.com/top20.htm
2,937,139,302 Internet users in the Top 20 countries in December 31, 2018

Internet Users in the World by Regions - December 31, 2017



Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 4,156,932,140 Internet users in December 31, 2017

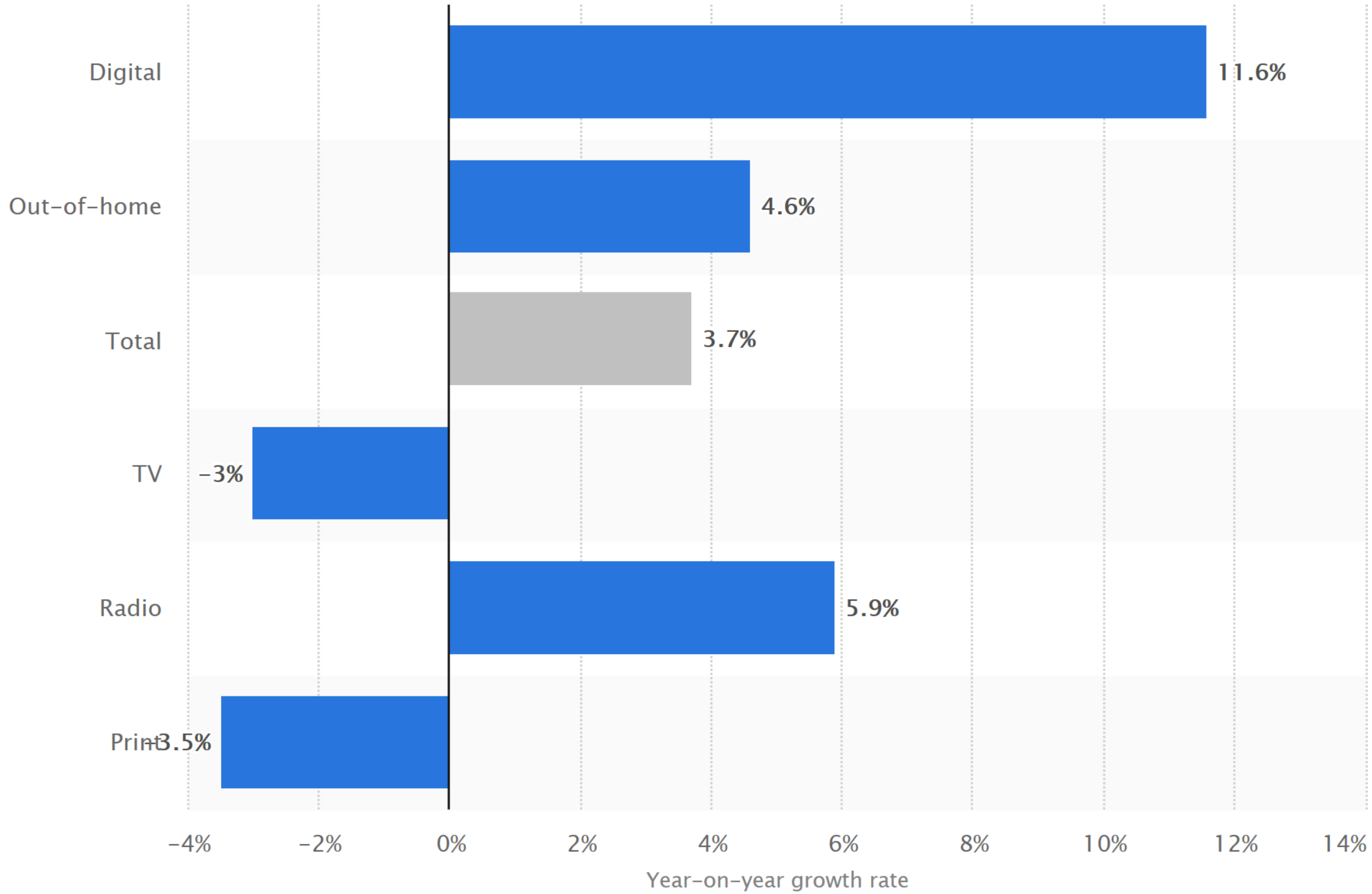
Internet World Penetration Rates by Geographic Regions - December 31, 2017



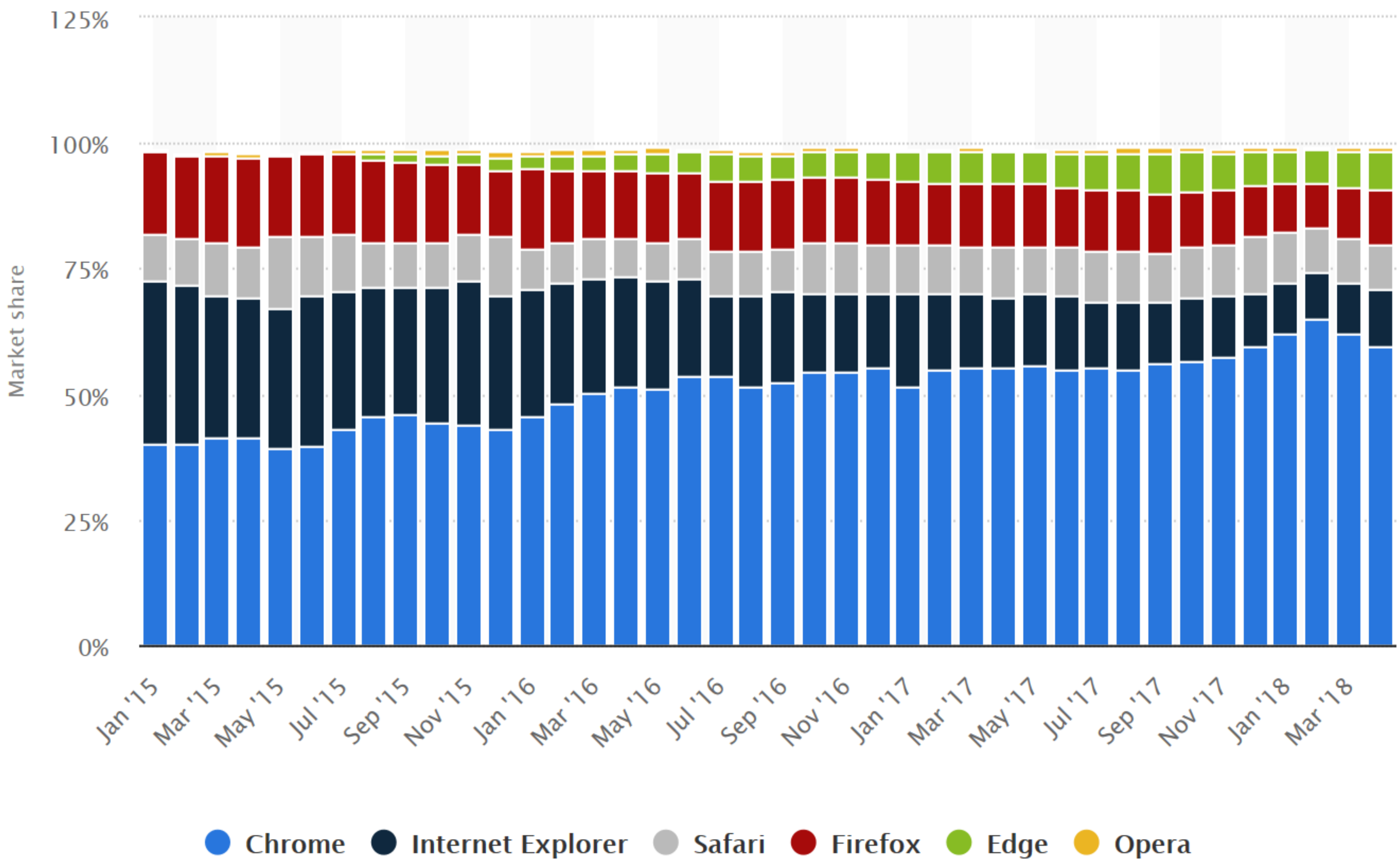
Source: Internet World Stats - www.internetworldstats.com/stats.htm
Penetration Rates are based on a world population of 7,634,758,428 and 4,156,932,140 estimated Internet users in December 31, 2017.

Business Advertising Trend 2018

1-11

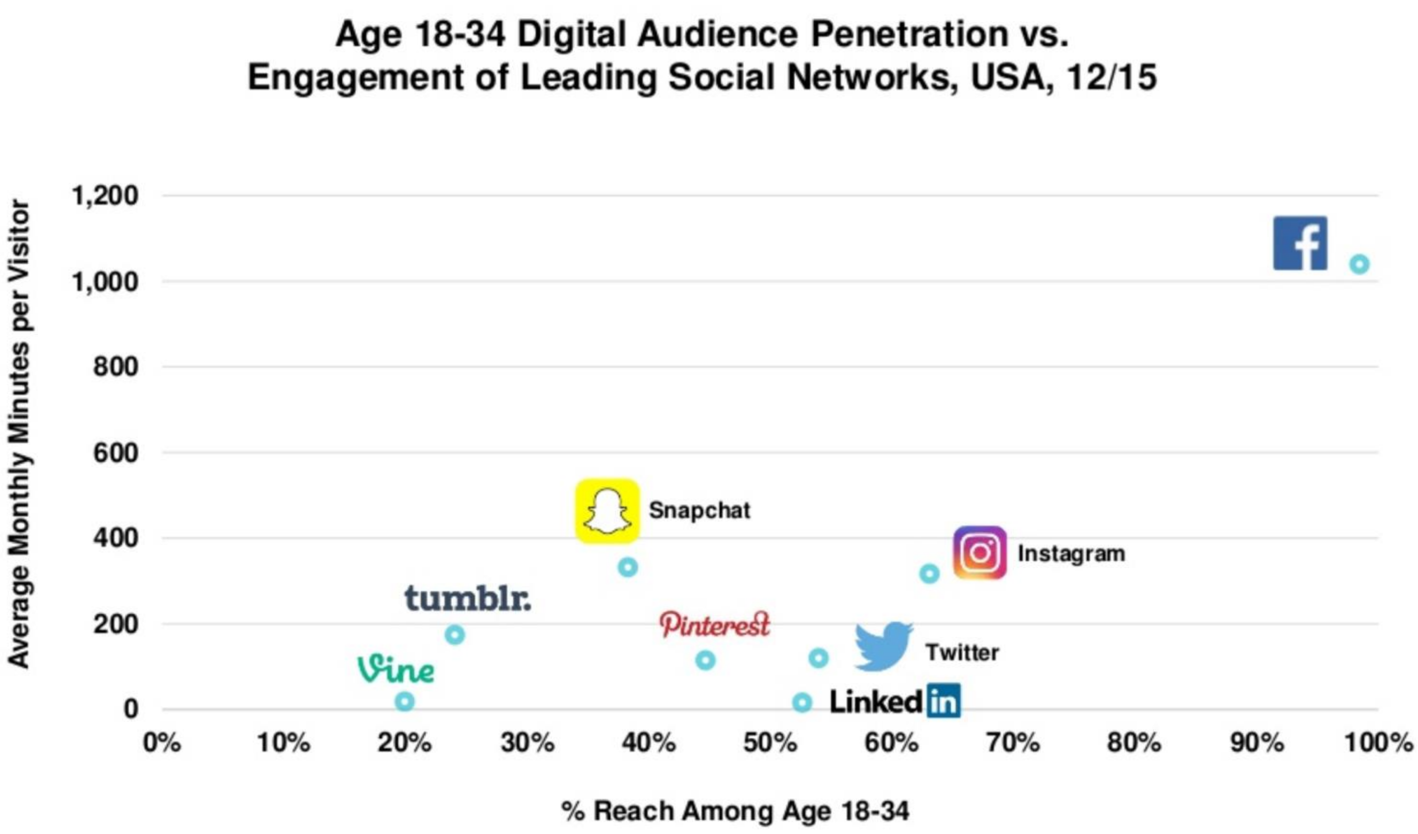


Browser Used

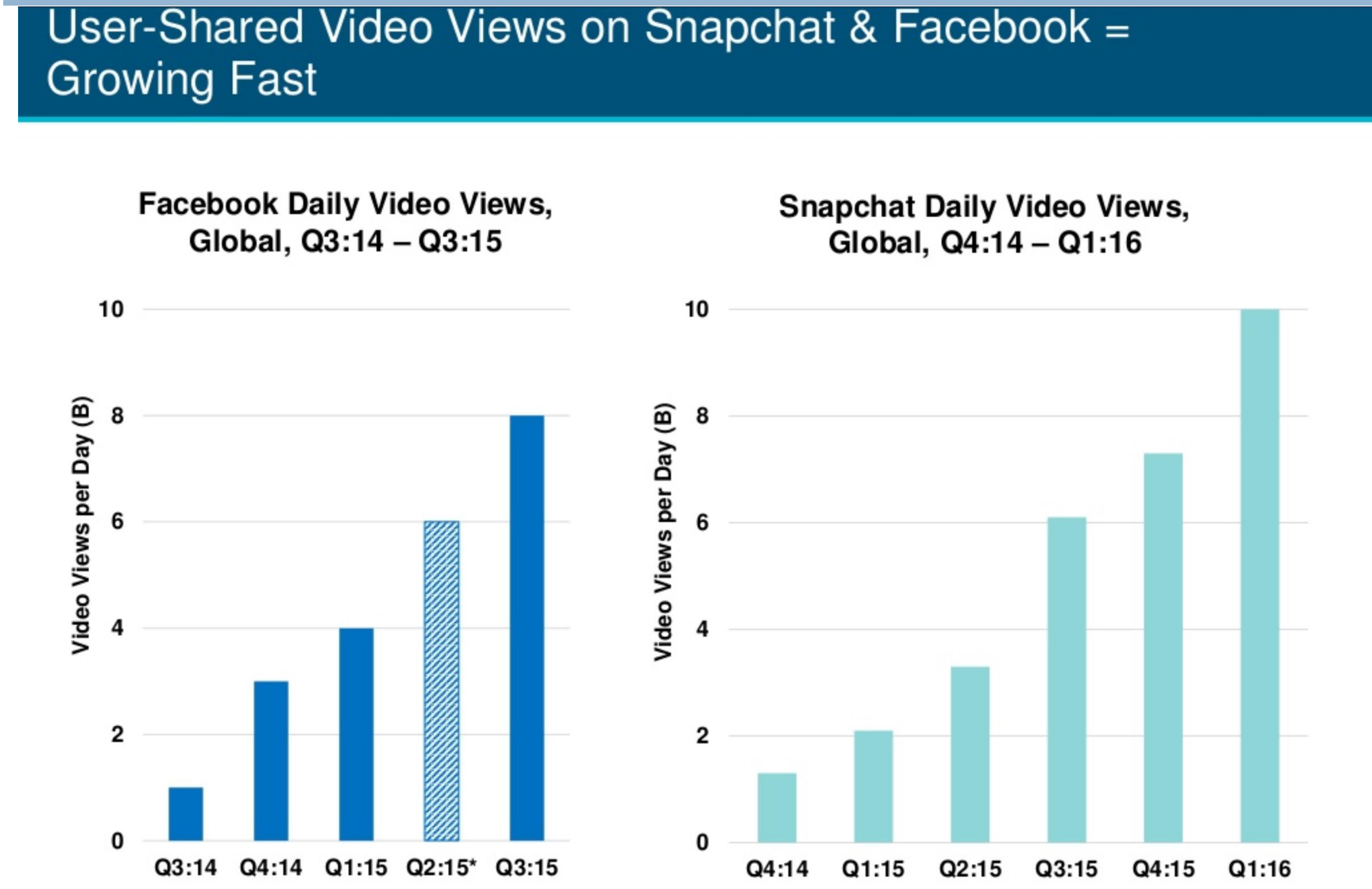


The State of the Internet 2016

Millennial Social Network Engagement Leaders = Visual...
Facebook / Snapchat / Instagram...



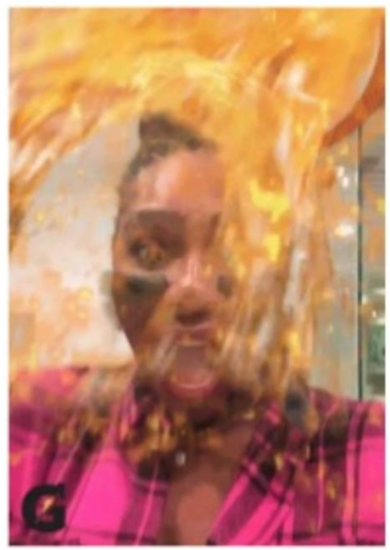
The State of the Internet 2016



What Are We Viewing?

Taco Bell Cinco de Mayo Lens
224MM Views on Snapchat
5/5/16

Gatorade Super Bowl Lens
165MM Views on Snapchat
2/7/16



Iron Man Filter from MSQRD
8MM+ Views on Facebook
3/9/16

Average Snapchatter Plays With Sponsored Lens for
20 Seconds

Average Measured Connection Speed

	Country/Region	Q3 2016 Avg. Mbps	QoQ Change	YoY Change
–	Global	6.3	2.3%	21%
1	South Korea	26.3	-2.5%	28%
2	Hong Kong	20.1	3.4%	27%
3	Norway	20.0	-0.2%	22%
4	Sweden	19.7	4.6%	13%
5	Switzerland	18.4	0.5%	14%
6	Singapore	18.2	5.3%	45%
7	Japan	18.0	5.1%	20%
8	Finland	17.6	0%	19%
9	Netherlands	17.3	2.1%	11%
10	Latvia	16.9	-3.5%	16%

High Broadband(>10Mbps) Connectivity

	Country/Region	% Above 10 Mbps	QoQ Change	YoY Change
–	Global	37%	5.4%	35%
1	South Korea	78%	-1.3%	16%
2	Japan	68%	4.9%	25%
3	Hong Kong	67%	2.5%	13%
4	Singapore	67%	-0.1%	32%
5	Iceland	65%	-1.4%	39%
6	Netherlands	65%	2.9%	8.7%
7	Switzerland	64%	-0.8%	6.2%
8	Belgium	64%	-0.3%	22%
9	Norway	64%	-1.1%	18%
10	Bulgaria	63%	-0.7%	26%

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

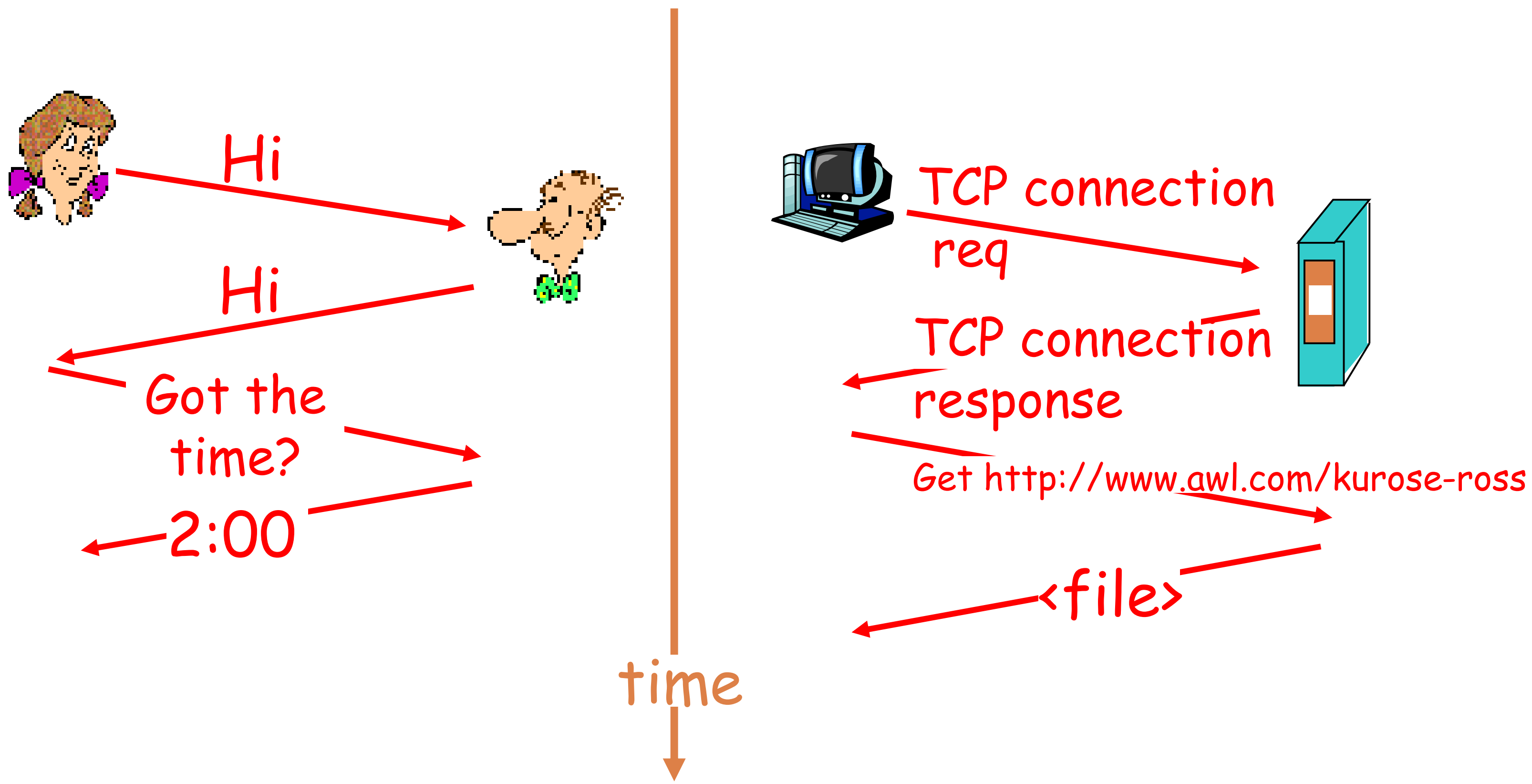
Test!

protocols define

- Format and order of msgs sent and received among network entities
- actions taken on msg transmission, receipt

What’s a protocol?

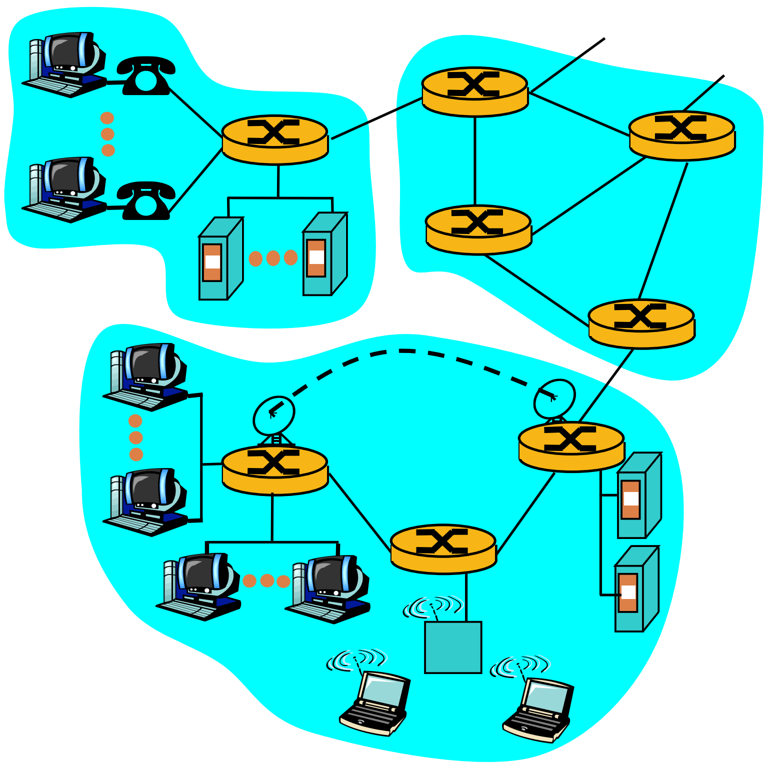
a human protocol and a computer network protocol:



Network Edge

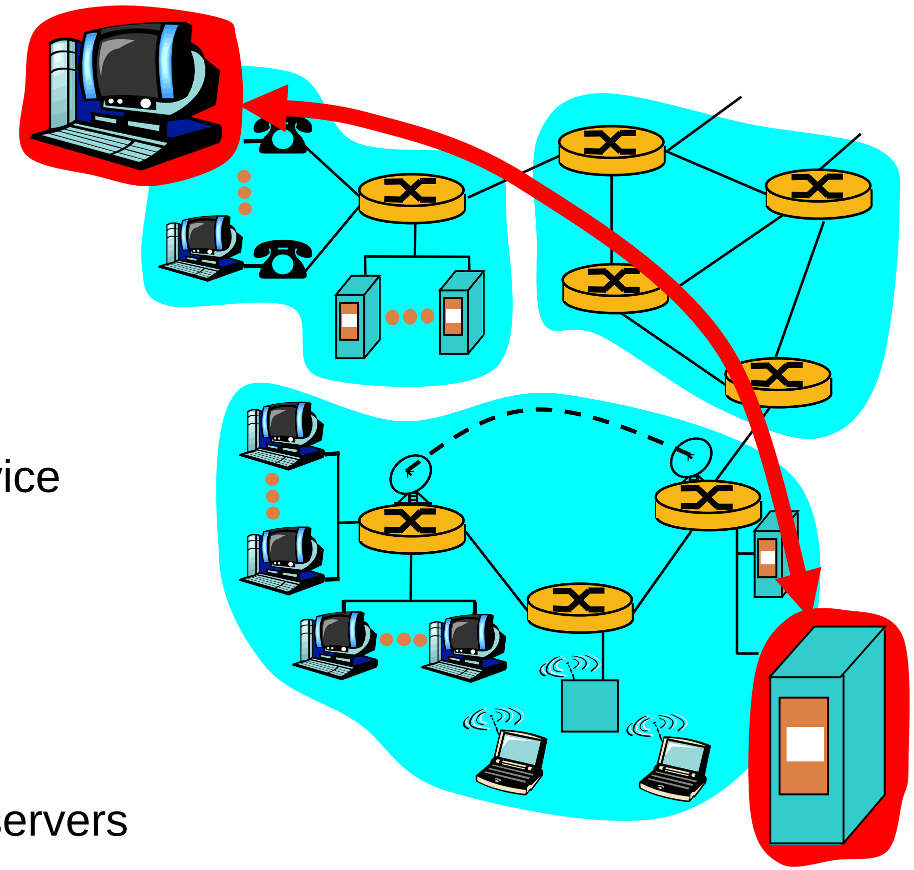
A closer look at network structure:

- network edge: applications and hosts
- network core:
  - Routers, network services
  - network of networks
- access networks, physical media: communication links



The network edge: From hardware point of view

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at “edge of network”
- Communication Models:
  - 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. Gnutella, KaZaA
  - Hybrid



Network edge: From service point of view

Connection Oriented Service

Goal: data transfer between end systems

- *handshaking:* setup (prepare for) data transfer ahead of time
  - human protocol: Hello, hello back
  - Machines: *set up "state"* in two communicating hosts
- Protocol used in this service:
  - TCP - Transmission Control Protocol
  - Internet's connection-oriented service

TCP service [RFC 793]

- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won't overwhelm receiver
- *congestion control:*
  - senders "slow down sending rate" when network congested

Network edge:
From service point of view

Connectionless Service

Goal: data transfer between end systems

- same as before!

- Protocol used in this service:
  - UDP - User Datagram Protocol [RFC 768]
  - Connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

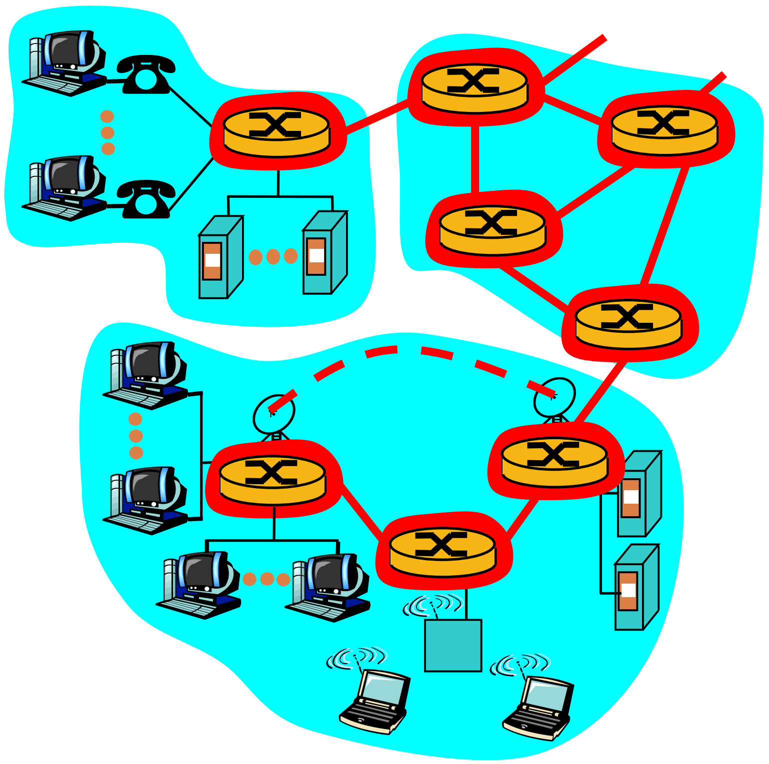
App's using UDP:

- streaming media, teleconferencing, DNS, Internet telephony

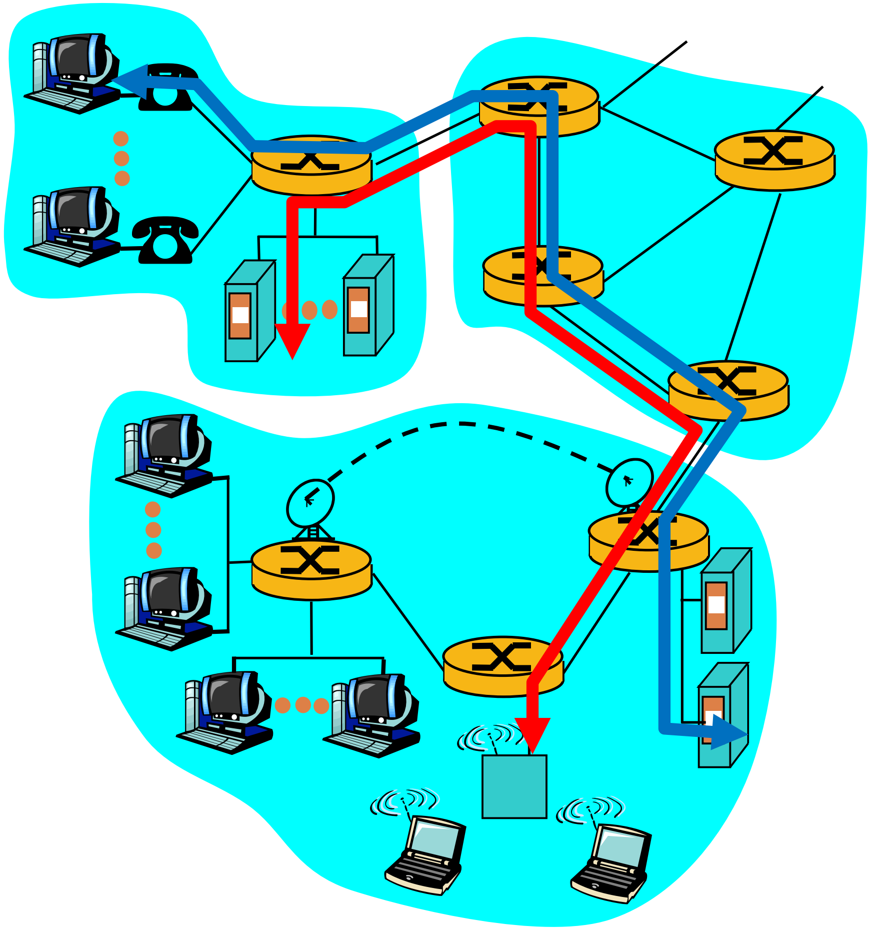
Network Core

The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: Reserve then use.
    - dedicated circuit per call: telephone net
  - packet-switching: First come first serve.
    - data sent thru net in discrete "chunks"



Network Core: Circuit Switching



End-end resources reserved for "call"

- link bandwidth
- switch capacity

Advantage:

- dedicated resources: no sharing
- circuit-like (guaranteed) performance

Drawback:

- 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)*

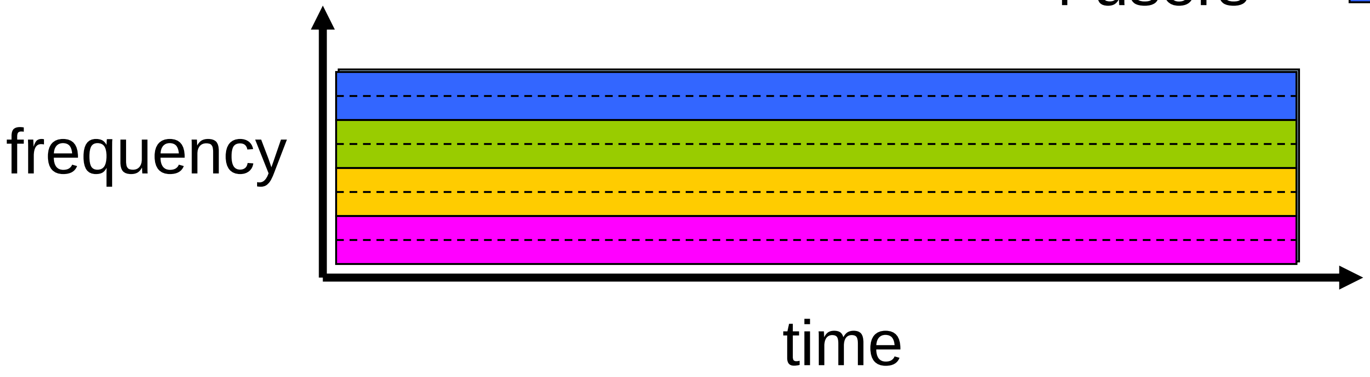
- How do one divide a link into several pieces?
  - This is call multiplexing
  - frequency division
  - time division

The width of a frequency band is called bandwidth

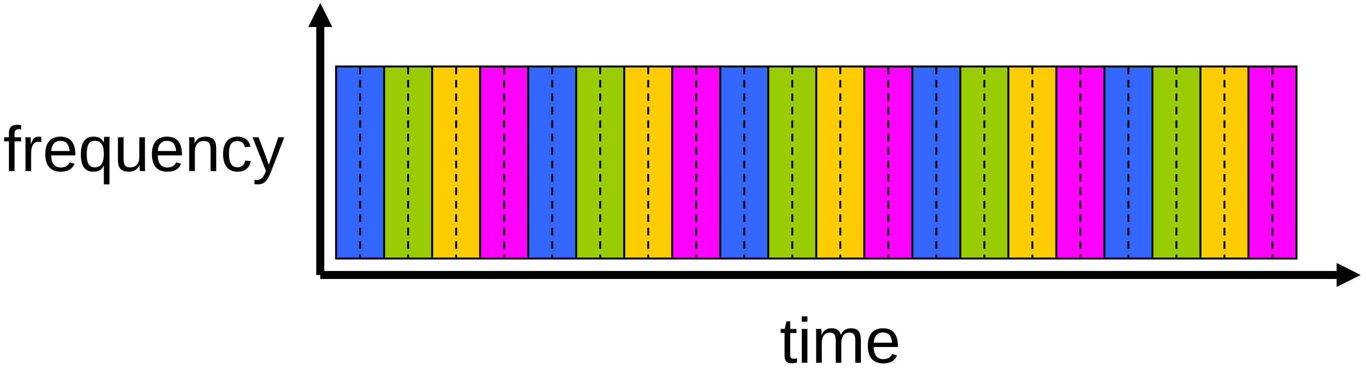
Circuit Switching: FDM and TDM

Example:
4 users

FDM



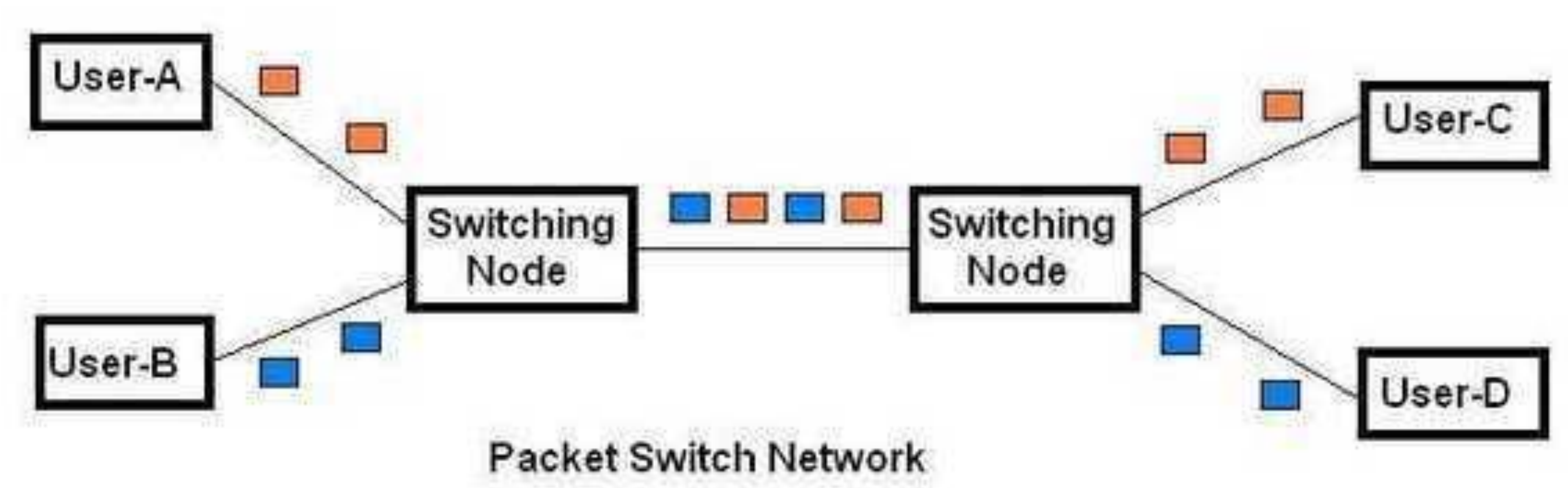
TDM



Circuit Switching

- The dedicated circuits are idle during **silent period**
  - Wasted!
- Underutilized
  - Some circuits maybe extremely busy transmitting data while other circuits may be at idle most of the time

Packet Switching



Network Core: Packet Switching

each end-end data stream divided into *packets*

- user A's and B's packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

Disadvantage:

→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 versus circuit switching

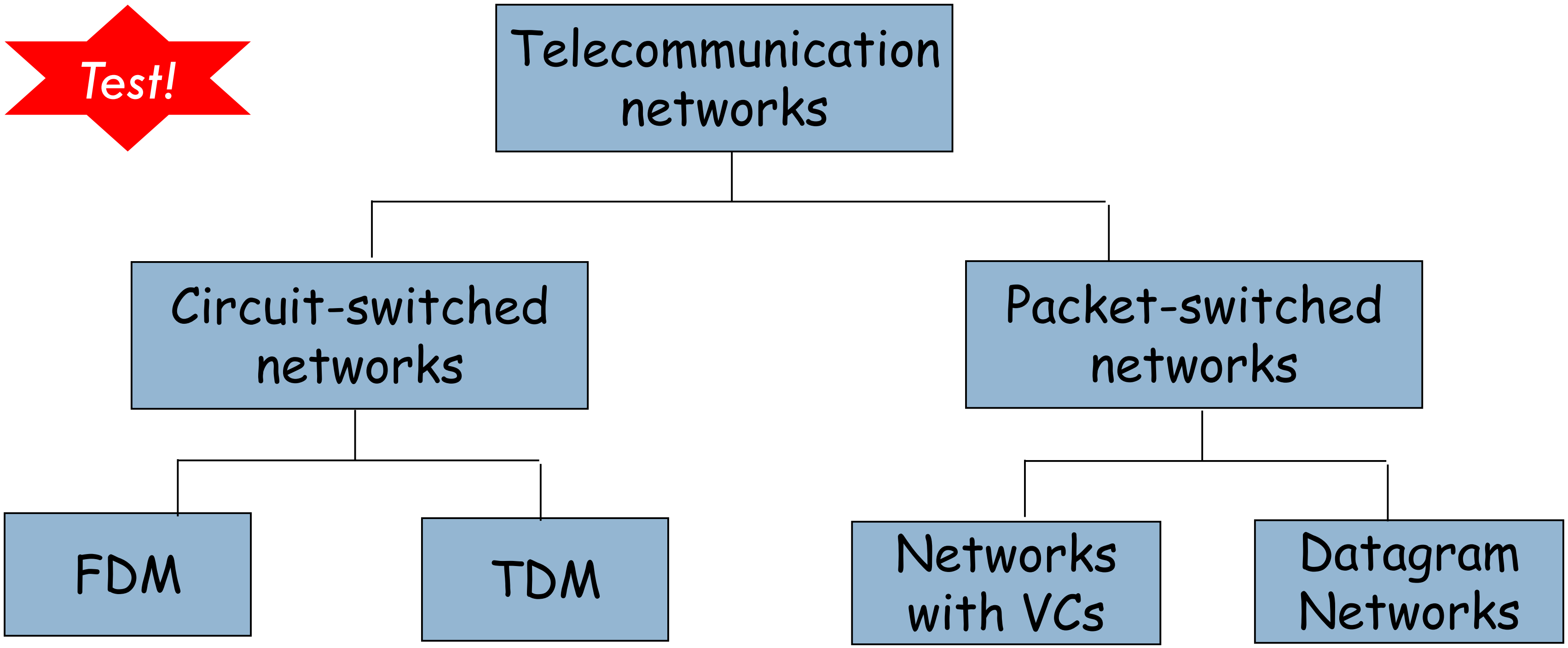
Is packet switching a “slam dunk winner?”

- Great for burst 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 (chapter 6)

Packet-switched networks: How does it forward packets?

- *Goal:* move packets through routers from source to destination
- Two broad classes of packet-switched networks: datagram & VCN
  - Differ in whether their switches use destination addresses or virtual-circuit numbers to forward packets to their destinations.
- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries a tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - *routers maintain per-call state*

Network Taxonomy



- Datagram network is *not* either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

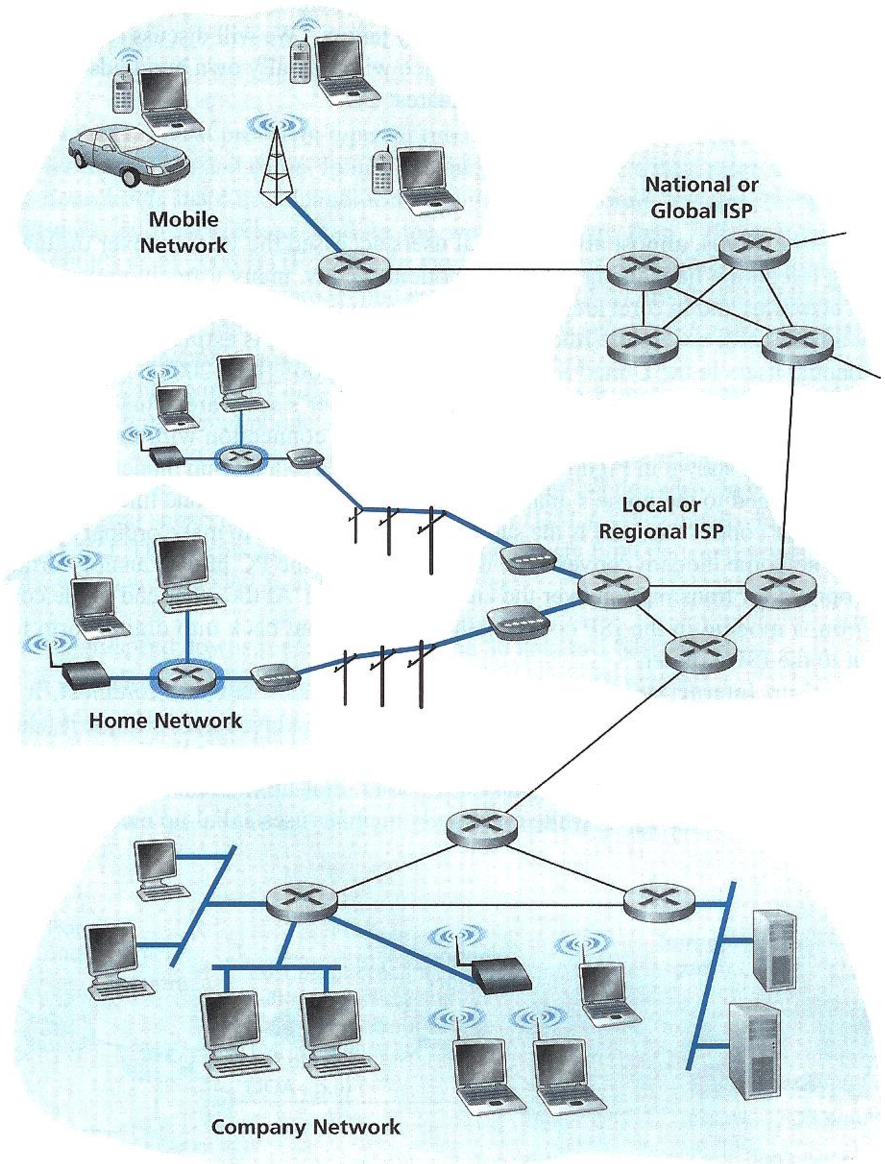
Access networks and physical media

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?



Technical Issues

- 8 bit = 1 Byte
- 1000 Bytes = 1KB
- 1000 KB = 1MB
- 1000 MB = 1GB
- 1000 GB = 1TB
- 1000 TB= 1Petabyte
- 1000 PB = 1 Exabyte
- 1000 EB = 1Zettabyte

- Group Work:

Which is faster?
20Mbps ? 300KBps?

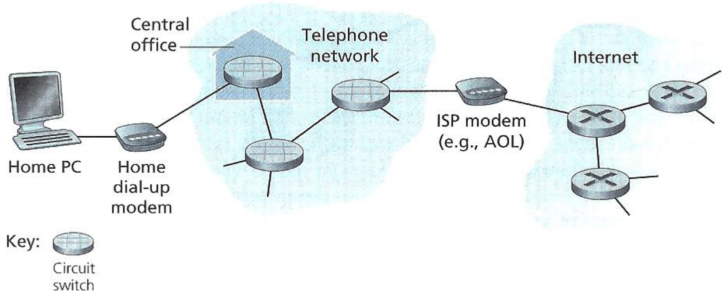
Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"
- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - FDM:

    50 kHz - 1 MHz for downstream

    4 kHz - 50 kHz for upstream

    0 kHz - 4 kHz for ordinary telephone



Residential access: cable modems

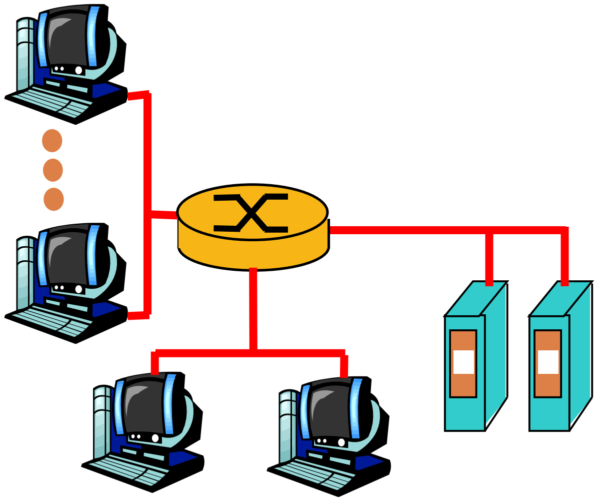
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- Network of cable and fiber attaches homes to ISP router
  - homes share access to router
- Deployment: available via cable TV companies

Group Work

- Find out the residential access available in your neighborhood
  - Server?
  - Bandwidth?
  - Price?

Company access: local area networks

- Company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbps, 100Mbps, Gigabit Ethernet, 10G Ethernet
- LANs: chapter 5

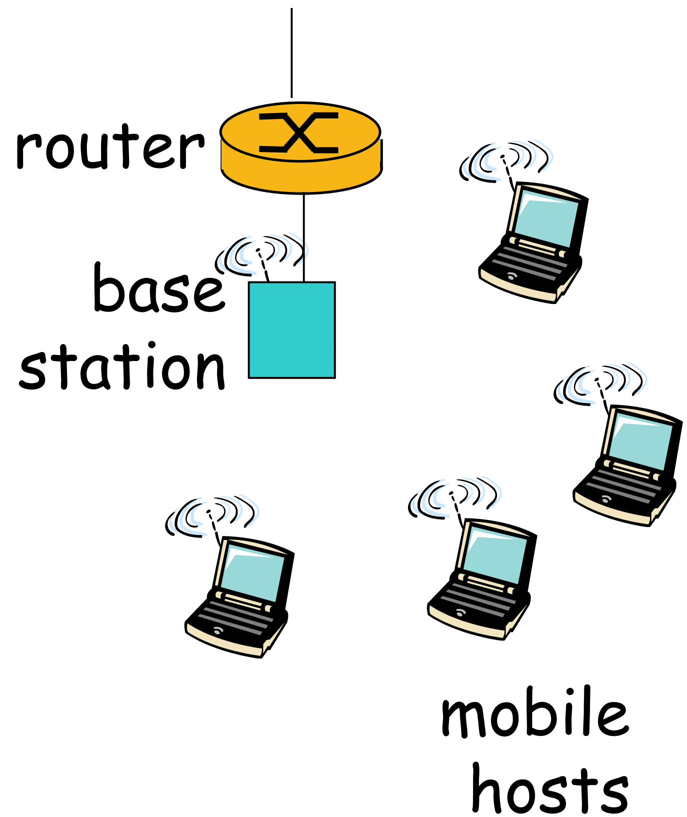


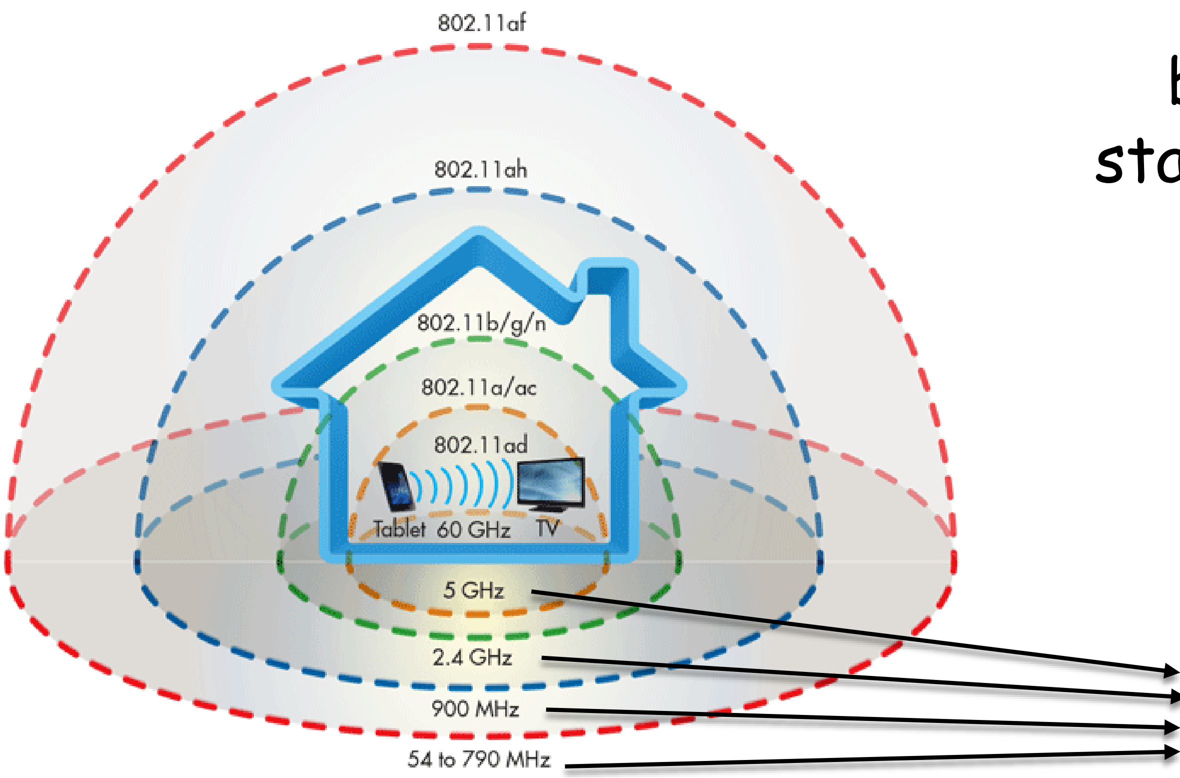
Group Work

- Find out the Business access available in your city
  - Server?
  - Bandwidth?
  - Price?

Wireless access networks

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





Notice the different frequencies!

Group Work

- Split into groups and find out fun facts of the following technology: Frequency? Bandwidth? Applications? Price?
  - 802.11b
  - 802.11g
  - 802.11n
  - 802.11ac
  - 802.11ad
  - 802.11ah
  - 802.11af
  - WAP
  - 3G
  - 4G
  - 5G

Wireless access networks

- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
  - 802.11g – 54Mbps
  - 802.11n – 2.4Ghz, and 5Ghz 300Mbps
  - 802.11ac – 2.4Ghz + 5Ghz, 1900Mbps or higher…
  - 802.11ad – very high frequency – 60Ghz, upto 7Gbps. Can be used for wireless hard drives, 4K display. Needs line of sight to operate.
  - 802.11ah(Wifi HaLow) – upto 1km, 26 channels around 900Mhz. Minimum 100kbps, as high as 40Mbps
  - 802.11af – uses MIMO, OFDM, UHF or VHF channels and channel binding to achieve up to 568.9Mbps. Several miles of range. Due to regulation, cannot continue to operate more than 48 hours using the same channels.

Wireless access networks

- Wider-area wireless access
  - 3G : 384 kbps
  - WAP/GPRS in Europe
  - 4G
    - WiMAX – 70Mbps over 50 kilometers
    - LTE – 100Mbps downstream and 50Mbps upstreadm. Short distance.
  - 5G?

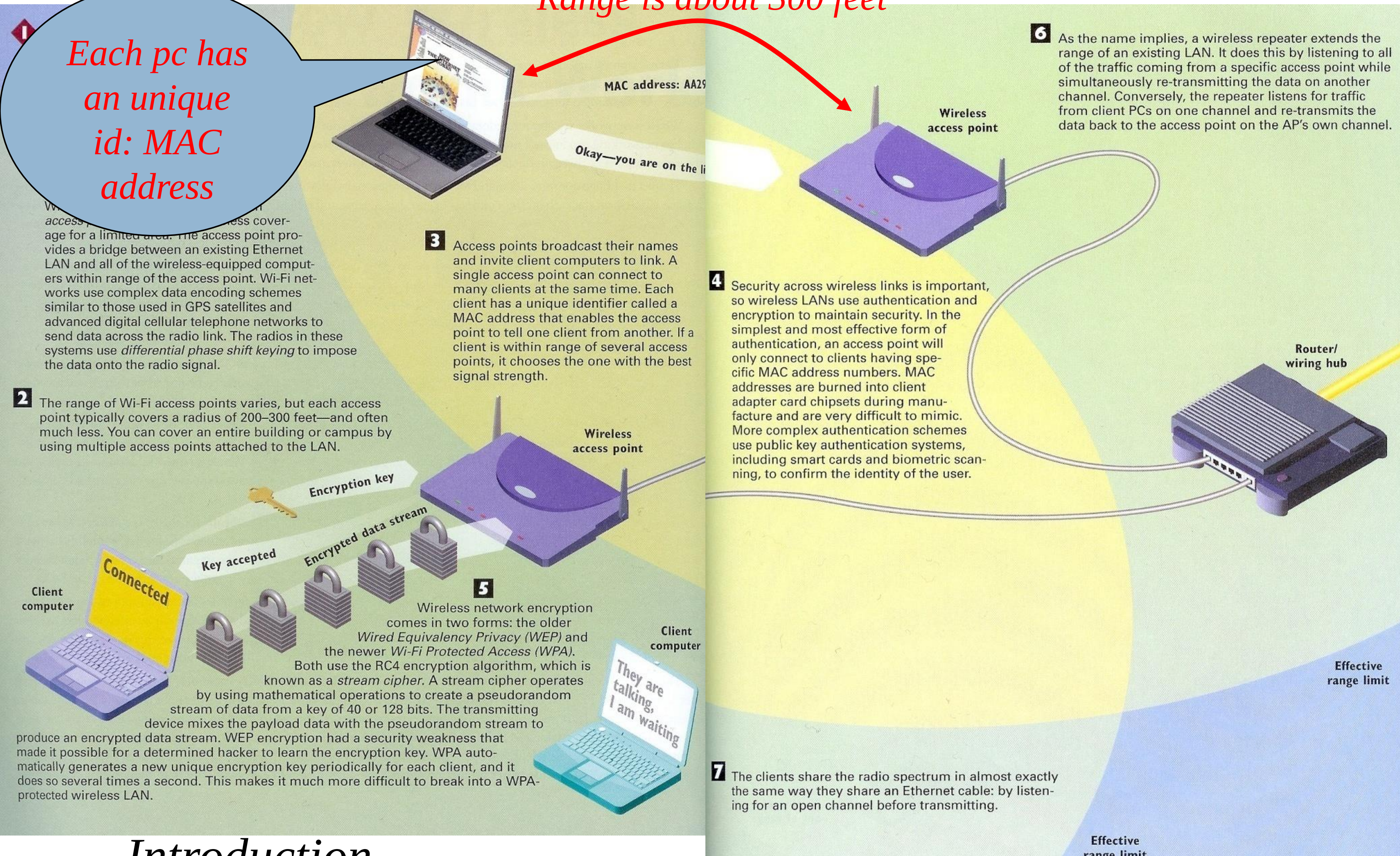
How Wireless Networks Work

- Almost all wireless LANs operate using one of several IEEE 802 standards
  - 802.11a, 802.11b, 802.11g and 802.11n (just passed 2009/09/12)
  - These standards define a method for transporting Ethernet network signals using a digital radio link
  - Wireless LAN use a device called an access point that provides wireless coverage for a limited area
  - The access point provides a bridge between an existing Ethernet LAN

How Wireless Networks Work

Range is about 300 feet

Each pc has an unique id: MAC address



1 W... access ... ess coverage for a limited area. The access point provides a bridge between an existing Ethernet LAN and all of the wireless-equipped computers within range of the access point. Wi-Fi networks use complex data encoding schemes similar to those used in GPS satellites and advanced digital cellular telephone networks to send data across the radio link. The radios in these systems use *differential phase shift keying* to impose the data onto the radio signal.

2 The range of Wi-Fi access points varies, but each access point typically covers a radius of 200–300 feet—and often much less. You can cover an entire building or campus by using multiple access points attached to the LAN.

3 Access points broadcast their names and invite client computers to link. A single access point can connect to many clients at the same time. Each client has a unique identifier called a MAC address that enables the access point to tell one client from another. If a client is within range of several access points, it chooses the one with the best signal strength.

4 Security across wireless links is important, so wireless LANs use authentication and encryption to maintain security. In the simplest and most effective form of authentication, an access point will only connect to clients having specific MAC address numbers. MAC addresses are burned into client adapter card chipsets during manufacture and are very difficult to mimic. More complex authentication schemes use public key authentication systems, including smart cards and biometric scanning, to confirm the identity of the user.

5 Wireless network encryption comes in two forms: the older *Wired Equivalency Privacy (WEP)* and the newer *Wi-Fi Protected Access (WPA)*. Both use the RC4 encryption algorithm, which is known as a *stream cipher*. A stream cipher operates by using mathematical operations to create a pseudorandom stream of data from a key of 40 or 128 bits. The transmitting device mixes the payload data with the pseudorandom stream to produce an encrypted data stream. WEP encryption had a security weakness that made it possible for a determined hacker to learn the encryption key. WPA automatically generates a new unique encryption key periodically for each client, and it does so several times a second. This makes it much more difficult to break into a WPA-protected wireless LAN.

6 As the name implies, a wireless repeater extends the range of an existing LAN. It does this by listening to all of the traffic coming from a specific access point while simultaneously re-transmitting the data on another channel. Conversely, the repeater listens for traffic from client PCs on one channel and re-transmits the data back to the access point on the AP's own channel.

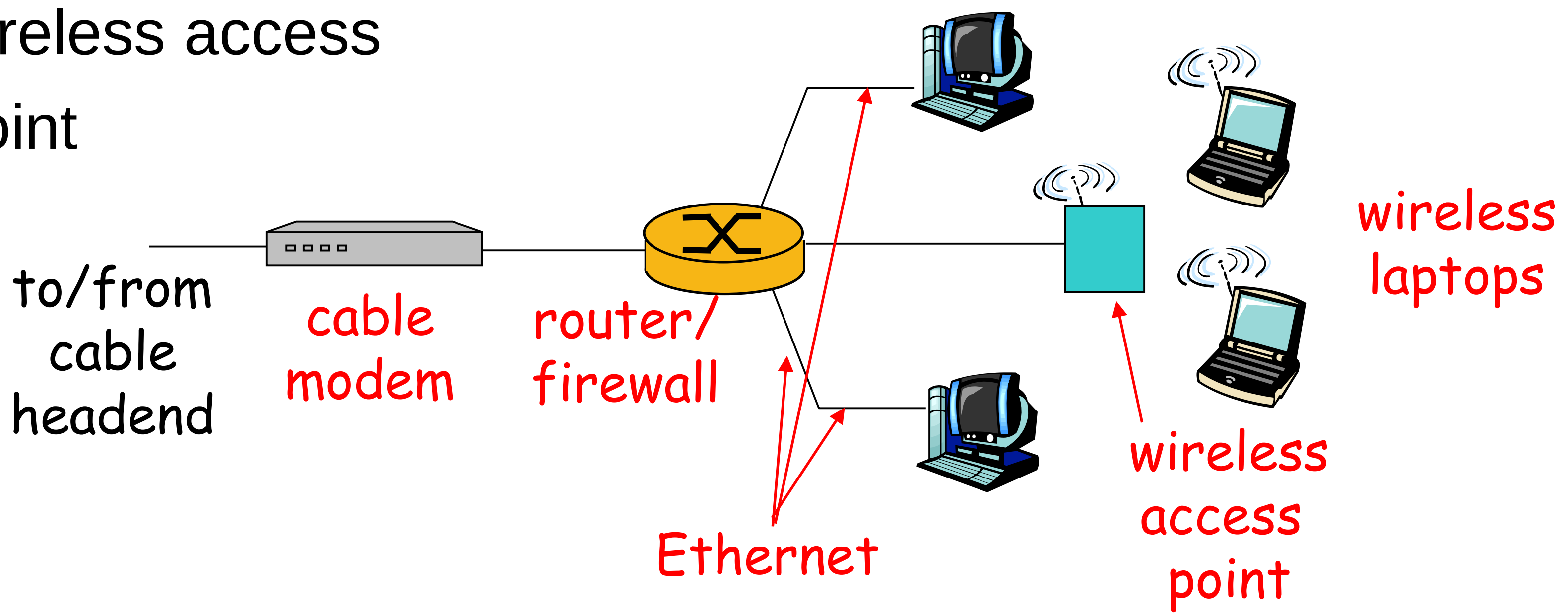
7 The clients share the radio spectrum in almost exactly the same way they share an Ethernet cable: by listening for an open channel before transmitting.

Introduction

Home networks

Typical home network components:

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



Physical Media

- Bit: propagates between transmitter/rcvr 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

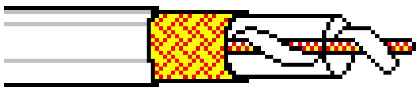
Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - Analog signaling, multiple channel on cable
  - HFC



Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 5 Gps)
- 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)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

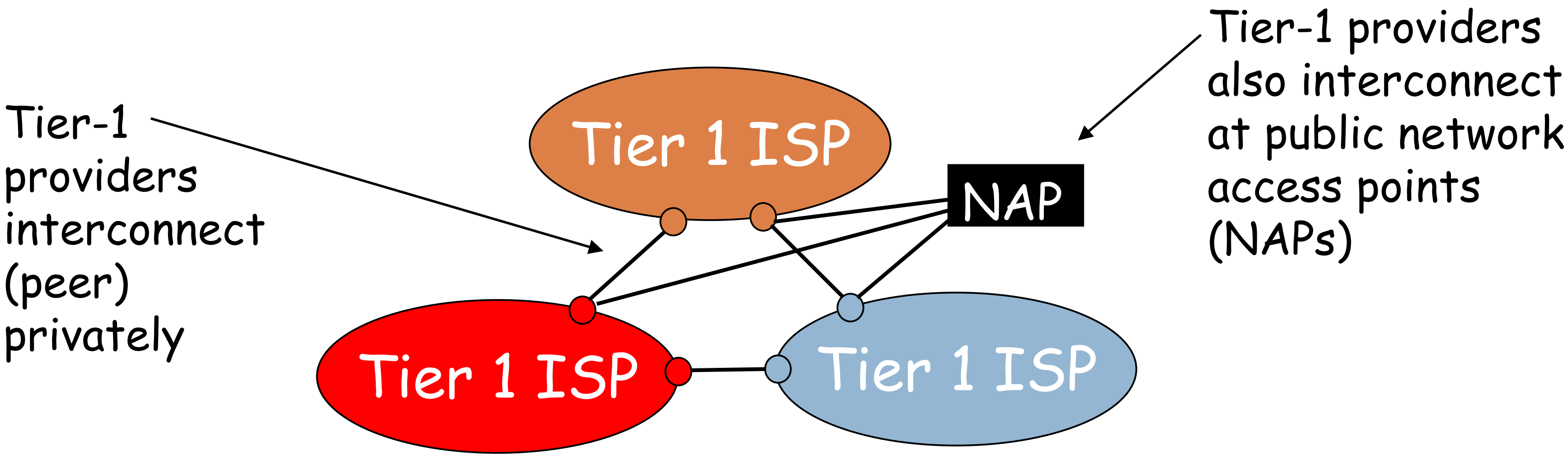
Group Work

- You have seen the physical media I passed around. Work with your group and describe: material used, physical properties(soft, hard, smelly, weight?), number of physical wires used, interesting properties that make them different than the rest.
  - Radio
  - Fiber Cable
  - Ethernet Cable
  - Coaxial Cable
  - Raw glass

Internet Structure and ISPs

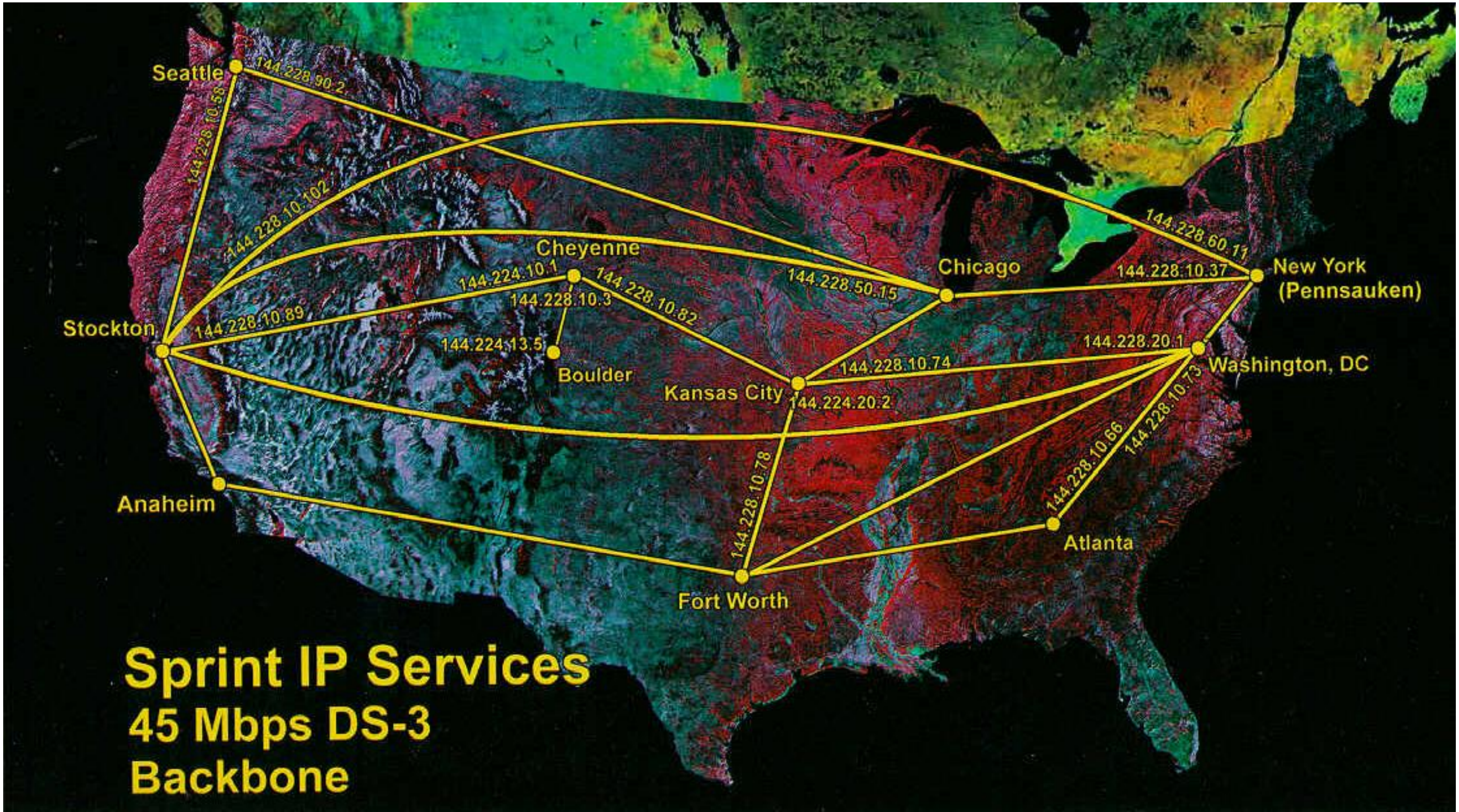
Internet structure: network of networks

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



Tier-1 ISP: e.g., Sprint

Sprint US backbone network

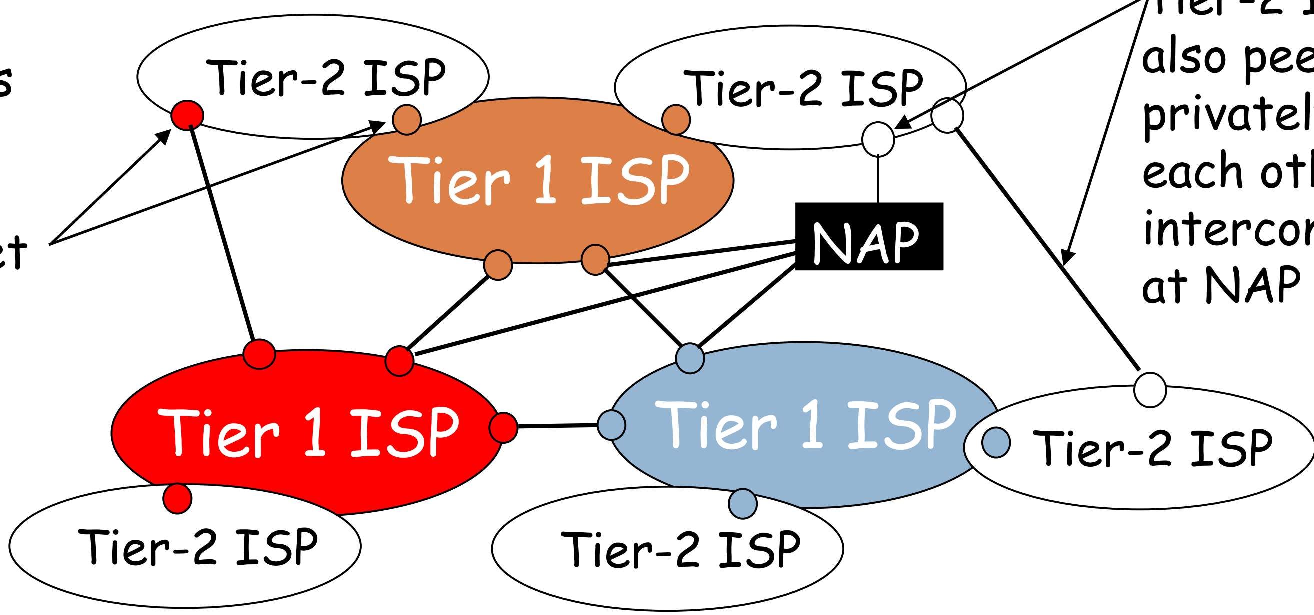


Internet structure: network of networks

- "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

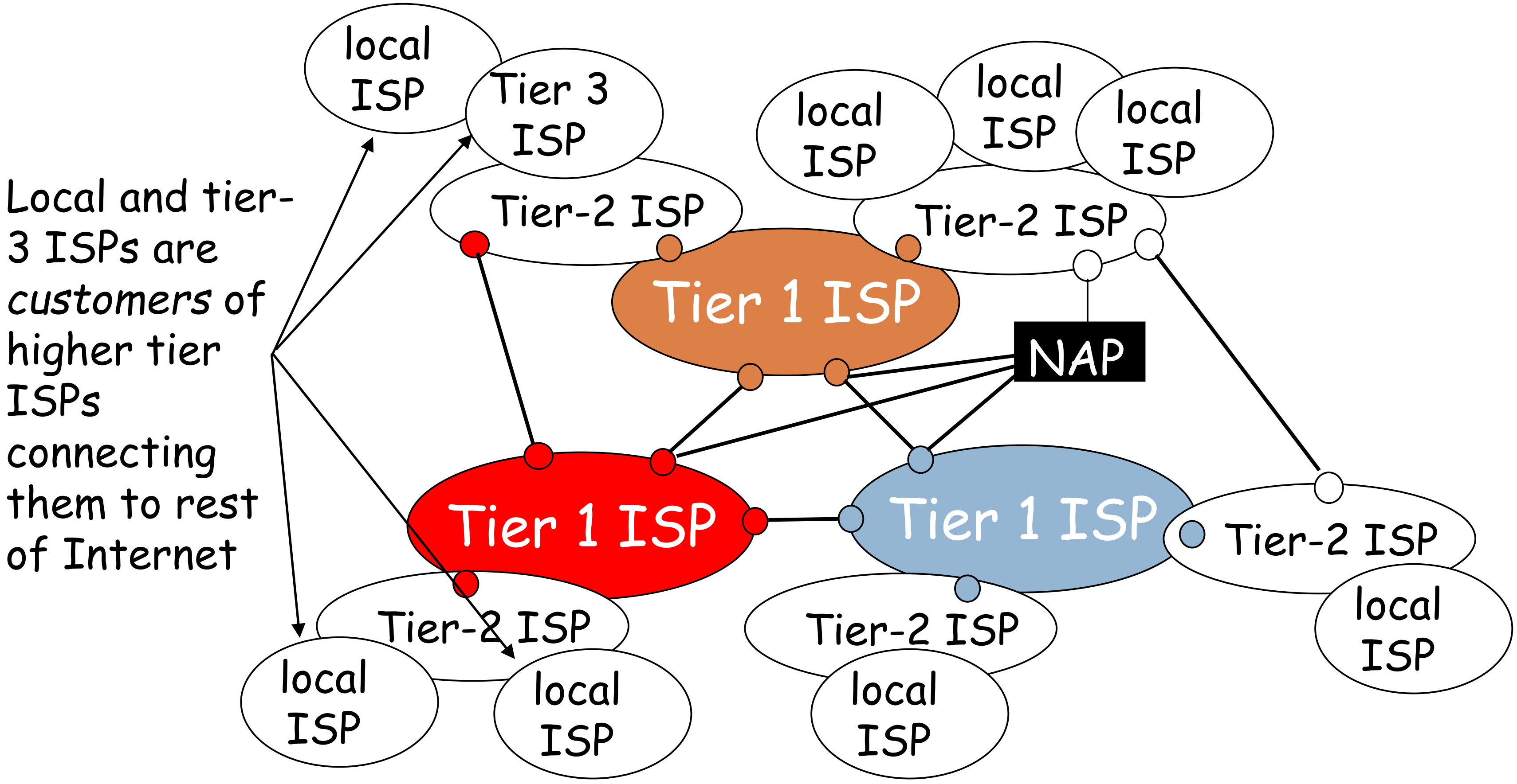
- tier-2 ISP is customer of tier-1 provider



Tier-2 ISPs also peer privately with each other, interconnect at NAP

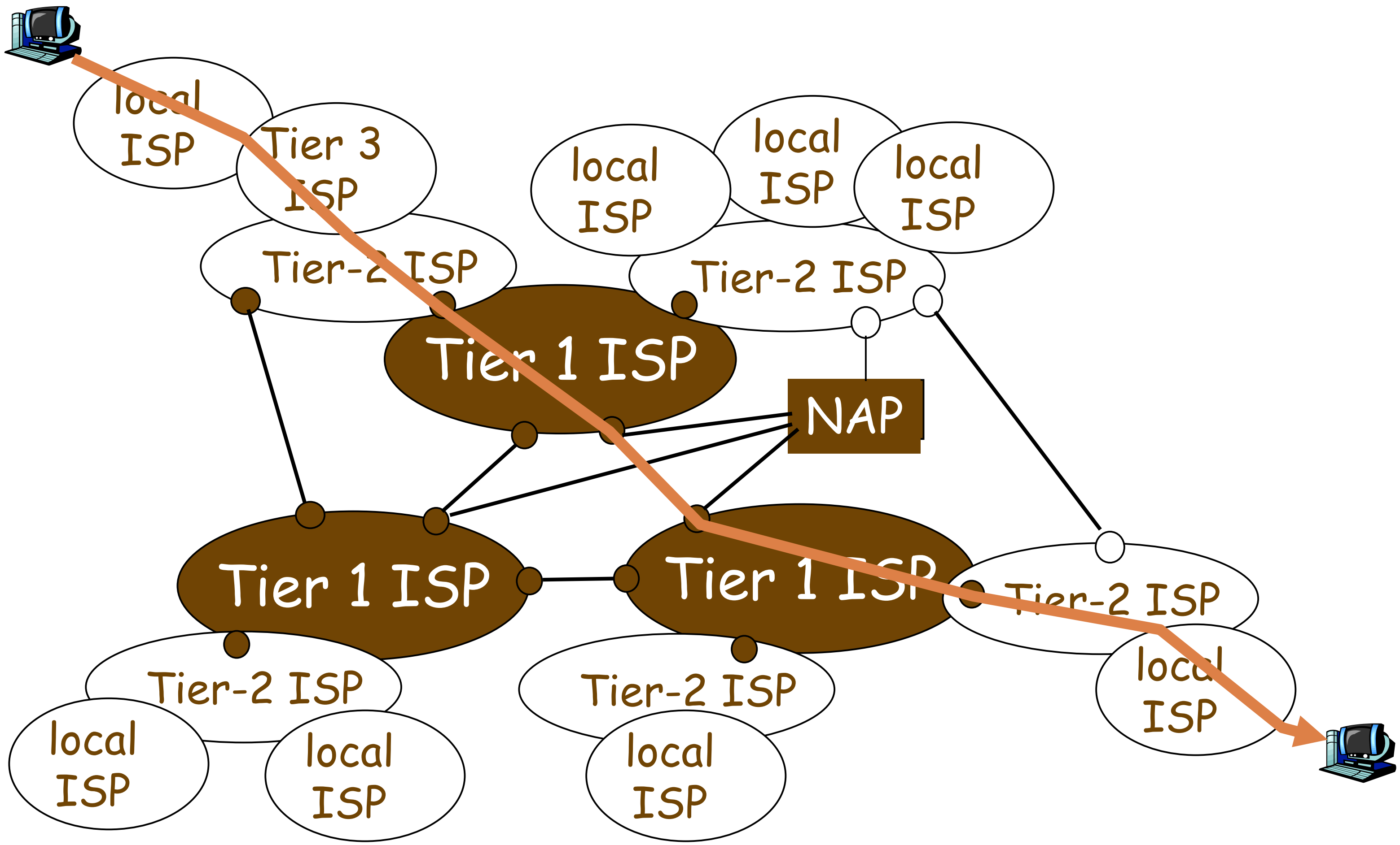
Internet structure: network of networks

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



Internet structure: network of networks

- a packet passes through many networks!



Delay & Loss in Packet-Switched Networks

How Networking Software Data Packaging Works

- Client sends requests to server
- Networking software detects a service request would redirect to a server.
  - It would package a directory request in an IP packet, appends TCP transmission controls and sends it to the LAN adapter
  - The LAN adapter further packages the request into an Ethernet frame
  - Each package contains its own addressing and error control information

How Networking Software Data Packaging Works

- Devices along the network examine both the Ethernet address (MAC-Address) and the IP address of each packet.
  - Some devices, like switches, take actions or grant permissions based on the MAC-layer address.
  - Routers take actions based on IP address
- At the destination server, the envelopes are unwrapped by networking software processes and put into order.
  - Re-join all received packets into original form

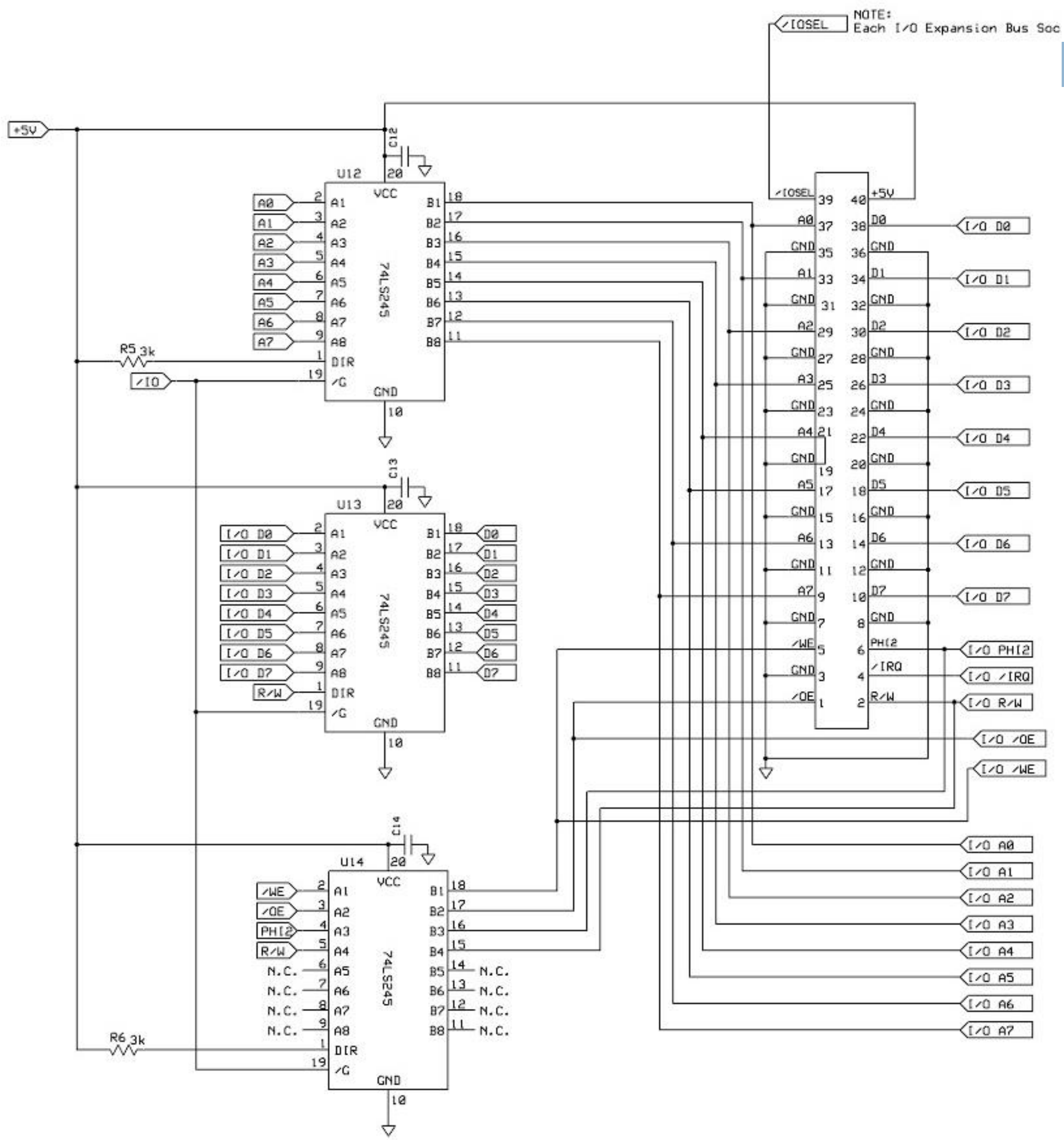
Group Work:
What are my Addresses?

- Open a terminal
- ifconfig
  - Find IPv4 Address
  - Find MAC addresses.
  - How many are there?
  - Can you interpret those entries?

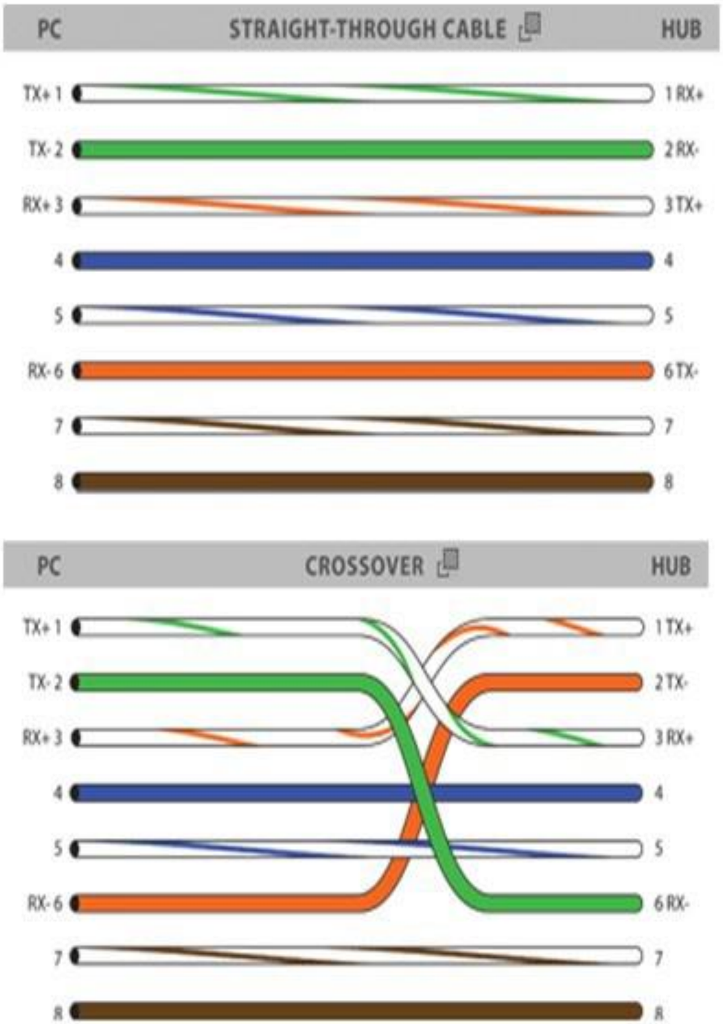
How Network Interface Cards Work

- Network Interface Cards (NICs) uses a special processor and routines stored in Read Only Memory (ROM)
- The processor receives commands from host computer and retrieve data from the contents of specific shared-memory locations within the host computer
  - Data was sent in parallel(see next slide)

Data Moving In I/O Bus



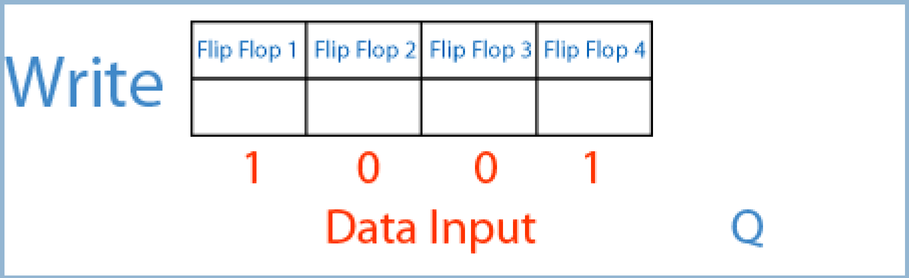
Data Moving In Ethernet



How Network Interface Cards Work

- Parallel data must break down to serial data
  - Network data is sent one bit at a time.
  - The processor uses shift registers to change the parallel data into a serial stream.
  - Then send over the cable

Shift Register:
Parallel-In, Serial-Out

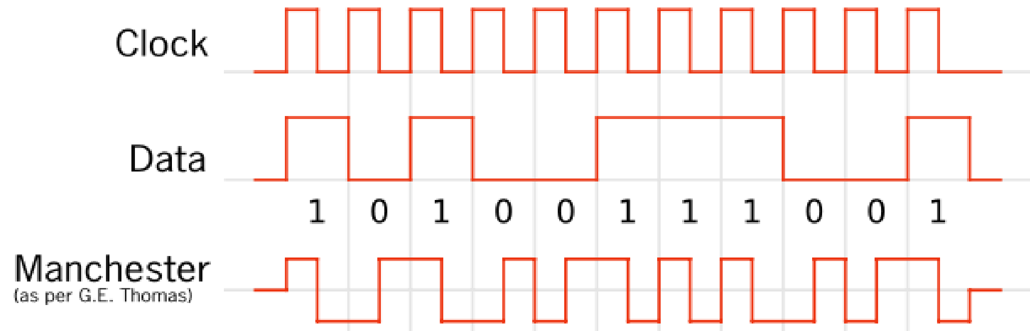


How Network Interface Cards Work

- The parallel-to-serial and fast-to-slow conversion is a necessary trade-off caused by distance
  - Higher change to expose to electromagnetic noise
  - Signal weaken
  - Trade-off between accuracy and speed
- For desktop, you have to use PCI bus type NICs
- For notebook, if no Ethernet sockets, you have to use PCMCIA or Express cards

How Network Interface Cards Work

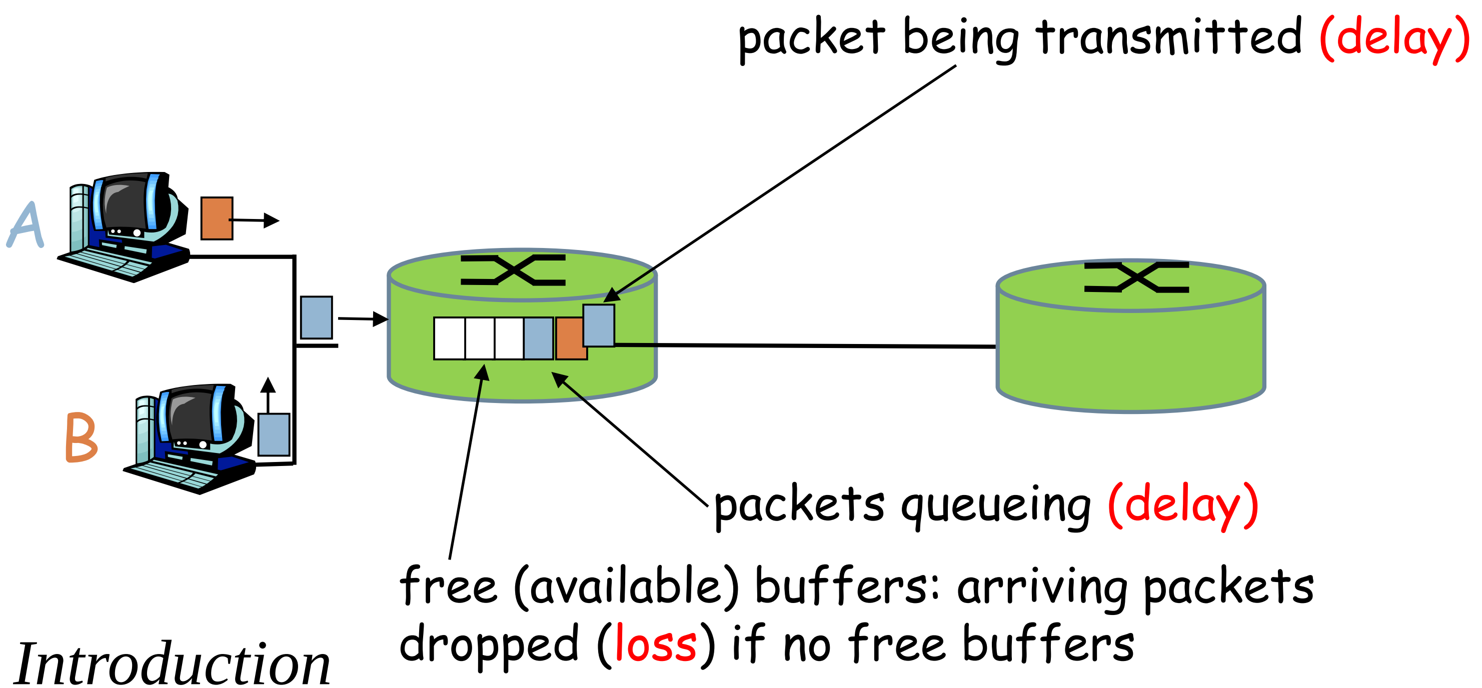
- When data sent to the network, they have to be encoded.
  - Manchester encoding is used
  - XOR clock and Data
- Rule of thumb
  - For the first bit of the sequence
    - To represent a binary 1 → change from 0 to +v
    - To represent a binary 0 → change from 0 to -v
  - For rest of the sequence
    - If the same signal → Change phase
    - If different signal → Keep phase then change phase
- At receiver, they have to use a device called digital phase locked loop (DPLL) to translate each change in the voltage level as a bit in digital stream



How do loss and delay occur?

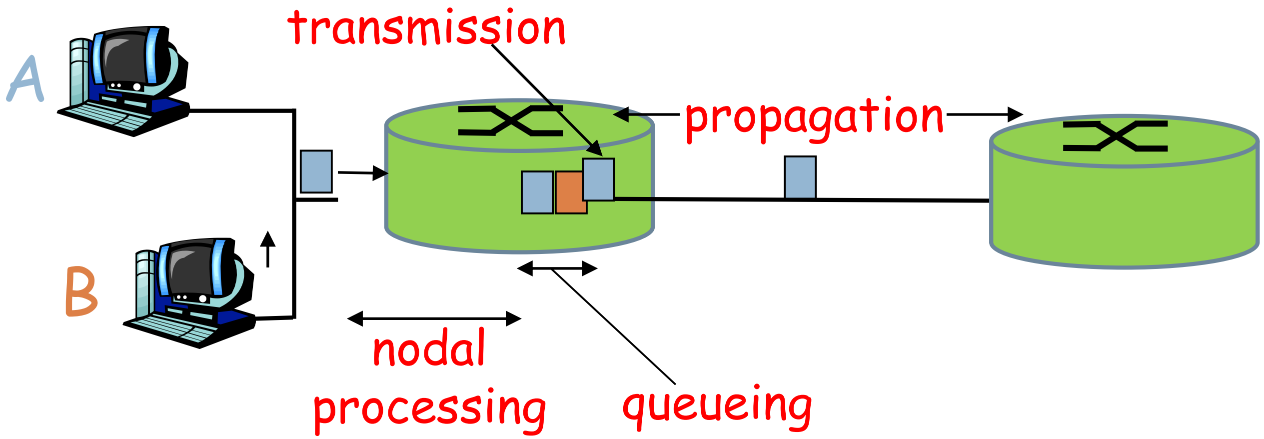
Packets *queue* in router buffers

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



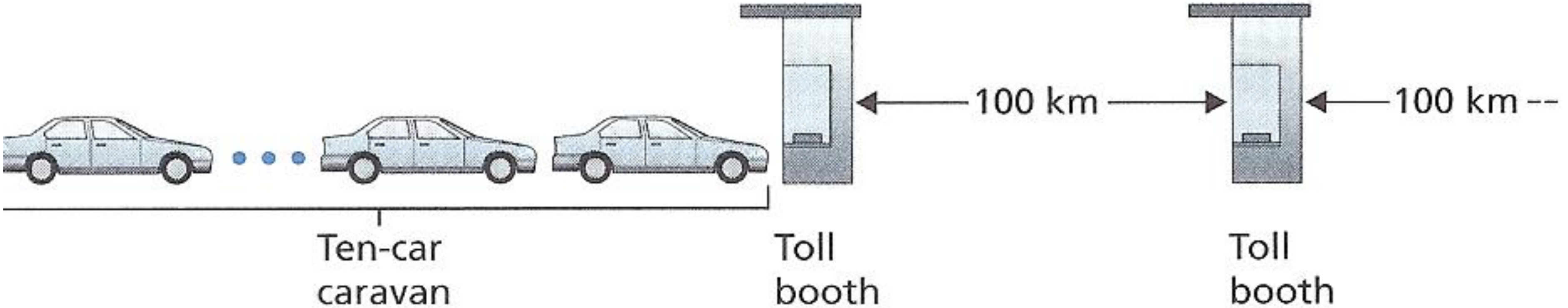
Four sources of packet delay

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



Example

- Consider a highway that has a tollbooth every 100 kilometers. Suppose that car travel on the highway at a rate of 100km/hour. Each tollbooth services a car at a rate of 12 seconds.
- How much time does it take to service 10 cars traveling together as a caravan.



"Real" Internet delays and routes

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

Three 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)

Trace Route in Ubuntu

- Install traceroute
  - sudo apt install inetutils-traceroute
  - sudo apt install traceroute

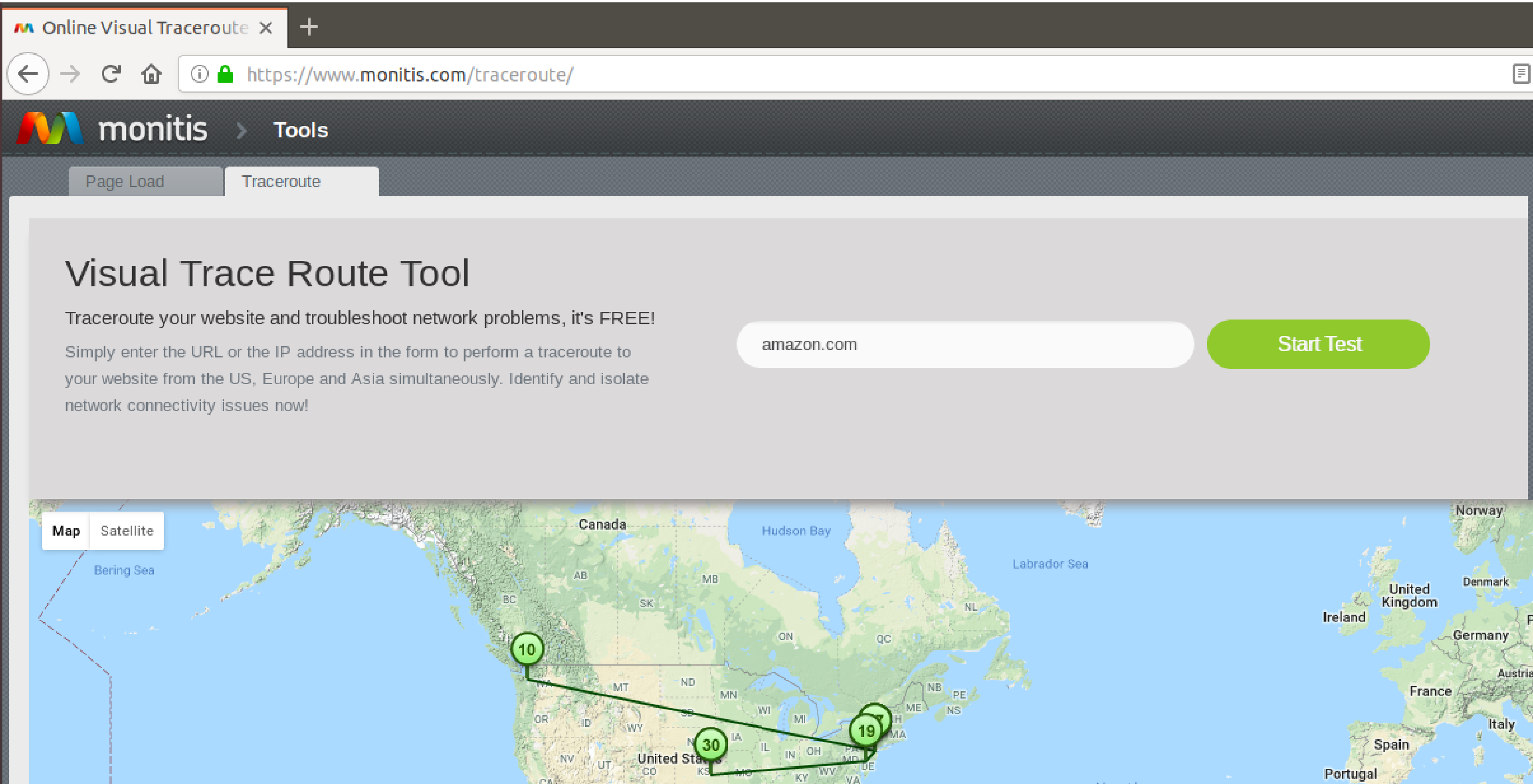
joseph@joseph-virtual-machine: ~

File Edit View Search Terminal Help

```
Processing triggers for man-db (2.8.3-2) ...
joseph@joseph-virtual-machine:~$ traceroute google.com
traceroute to google.com (64.233.177.139), 64 hops max
  1   *  *  *
  2   10.10.2.1  3.597ms  4.723ms  5.348ms
  3   204.116.250.169  5.612ms  7.791ms  7.418ms
  4   165.166.24.53  12.427ms  8.209ms  8.852ms
  5   *  *  165.166.24.18  13.147ms
  6   72.14.212.106  16.073ms  17.177ms  18.202ms
  7   108.170.249.44  18.210ms  29.248ms  16.113ms
  8   72.14.233.119  18.896ms  19.317ms  18.038ms
  9   209.85.142.153  15.769ms  23.382ms  17.153ms
 10   *  *  *
 11   *  *  *
 12   *  *  *
 13   *  *  *
 14   *  *  *
 15   *  *  *
 16   *  *  *
 17   *  *  *
 18   *  *  *
 19   64.233.177.139  17.739ms  17.055ms  17.930ms
joseph@joseph-virtual-machine:~$ ^C
joseph@joseph-virtual-machine:~$
```

Visual Traceroute

- Google Visual Trace Route



Packet loss

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

Protocol Layers, Service Models

Protocol “Layers”

Networks are complex!

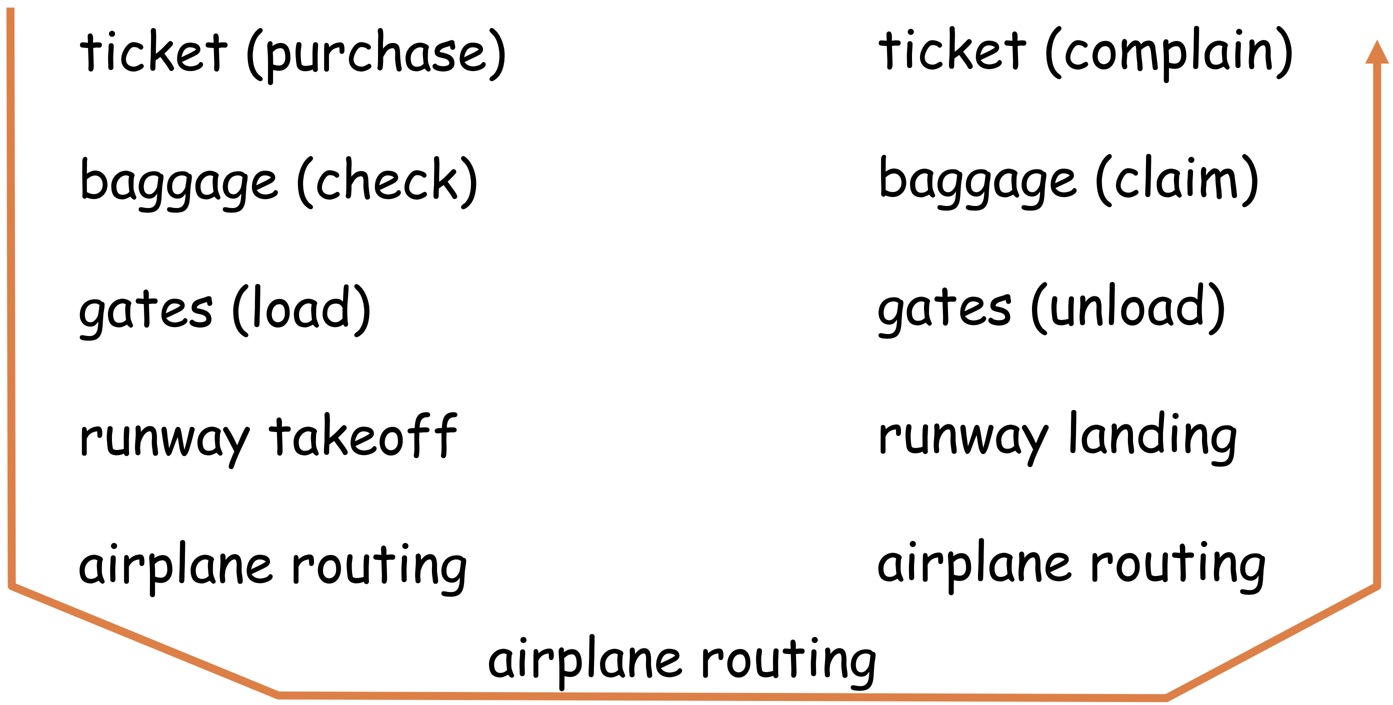
- many “pieces”:
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

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

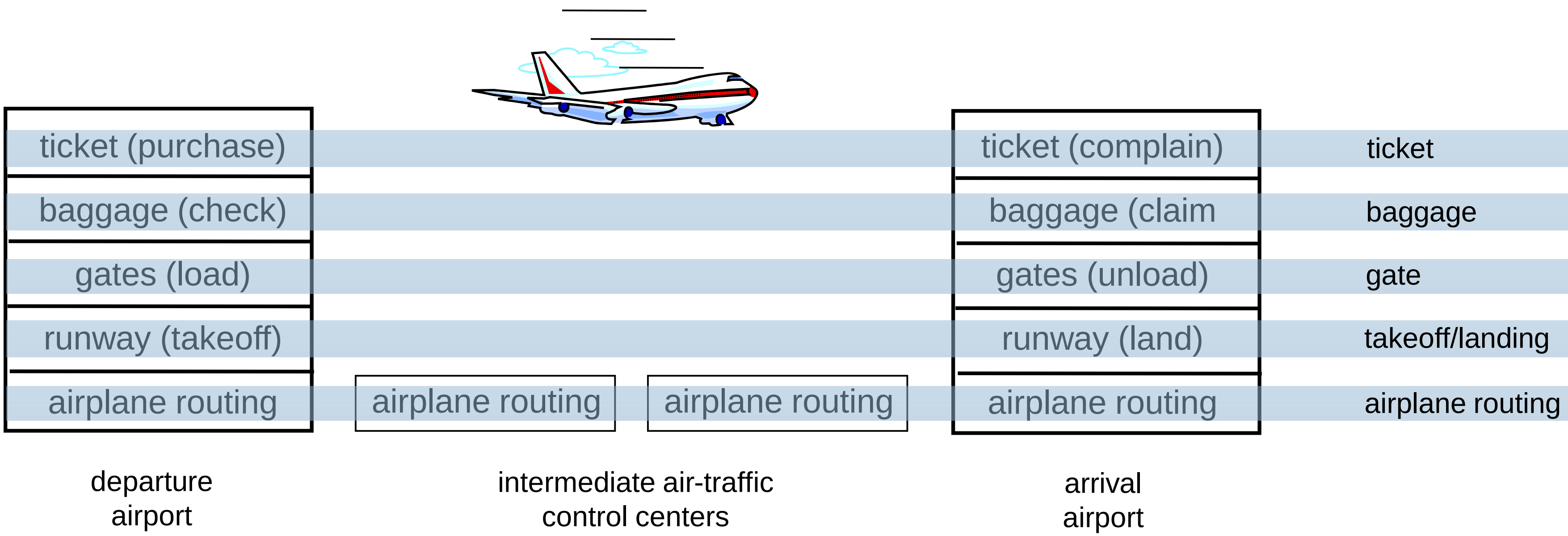
Or at least our discussion of networks?

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:

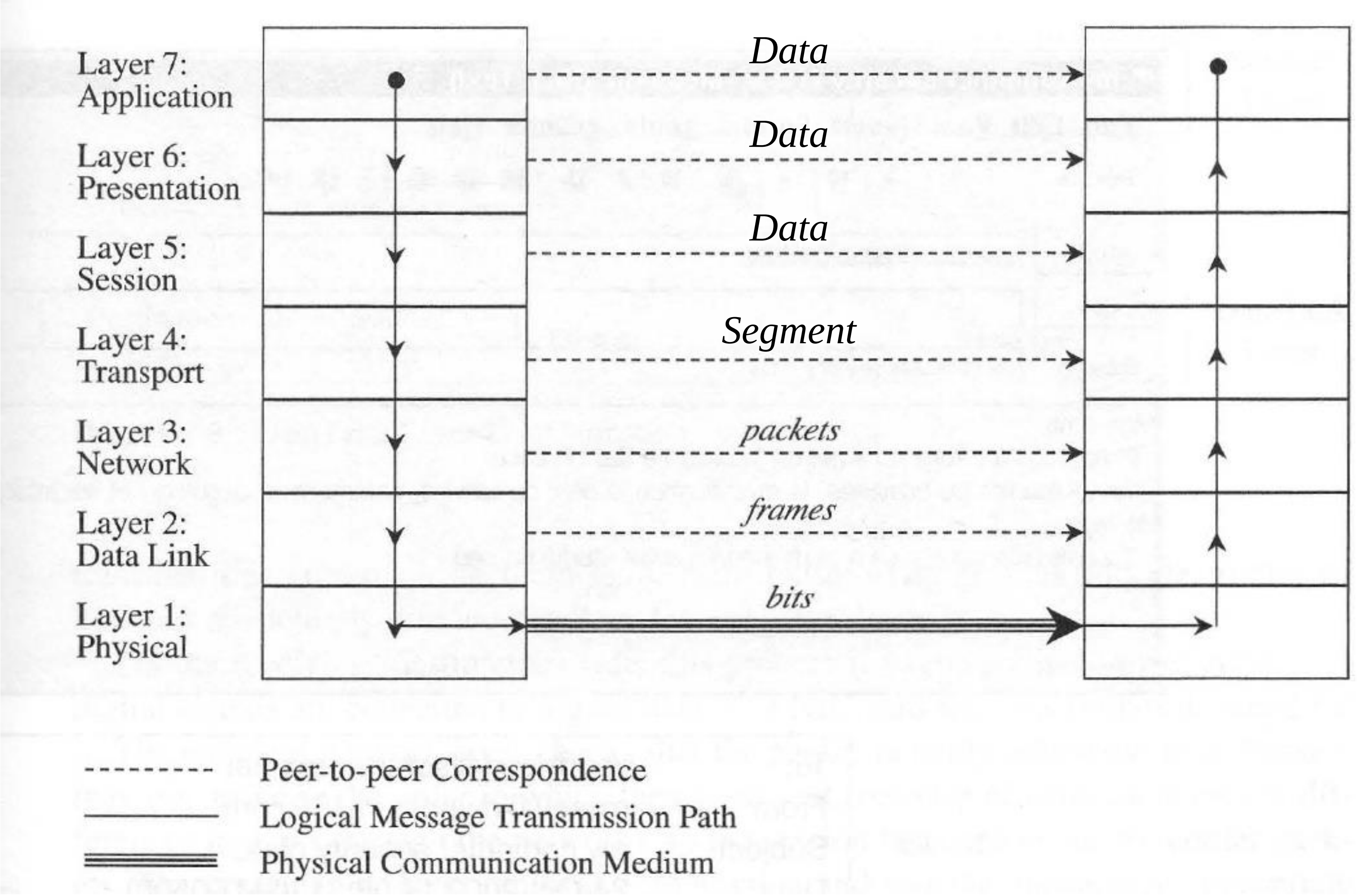
- Explicit structure allows identification, relationship of complex system's pieces
  - Layered reference model for discussion
- Modularization eases maintenance, updating of system
  - Change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't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

OSI Protocol Layer Levels

TABLE 7-1 OSI Protocol Layer Levels.

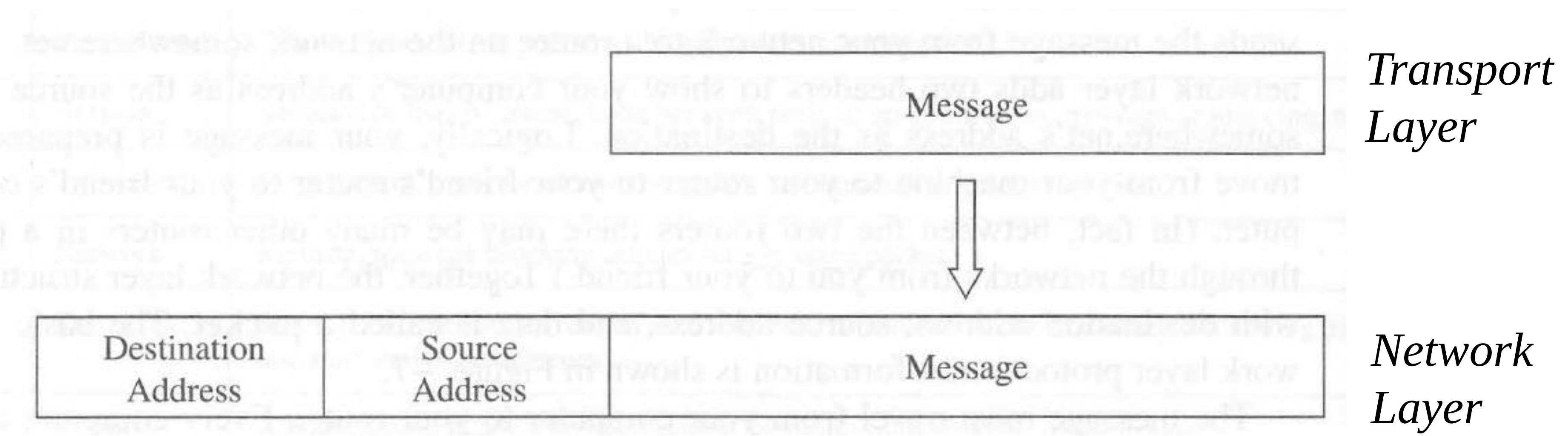
Layer	Name	Activity
7	Application	User-level data
6	Presentation	Standardized data appearance, blocking, text compression
5	Session	Sessions or logical connections between parts of an application; message sequencing, recovery
4	Transport	Flow control, end-to-end error detection and correction, priority service
3	Network	Routing, message blocking into uniformly sized packets
2	Data Link	Reliable data delivery over physical medium; transmission error recovery, separating packets into uniformly sized frames
1	Physical	Actual communication across physical medium; individual bit transmission

Encapsulation



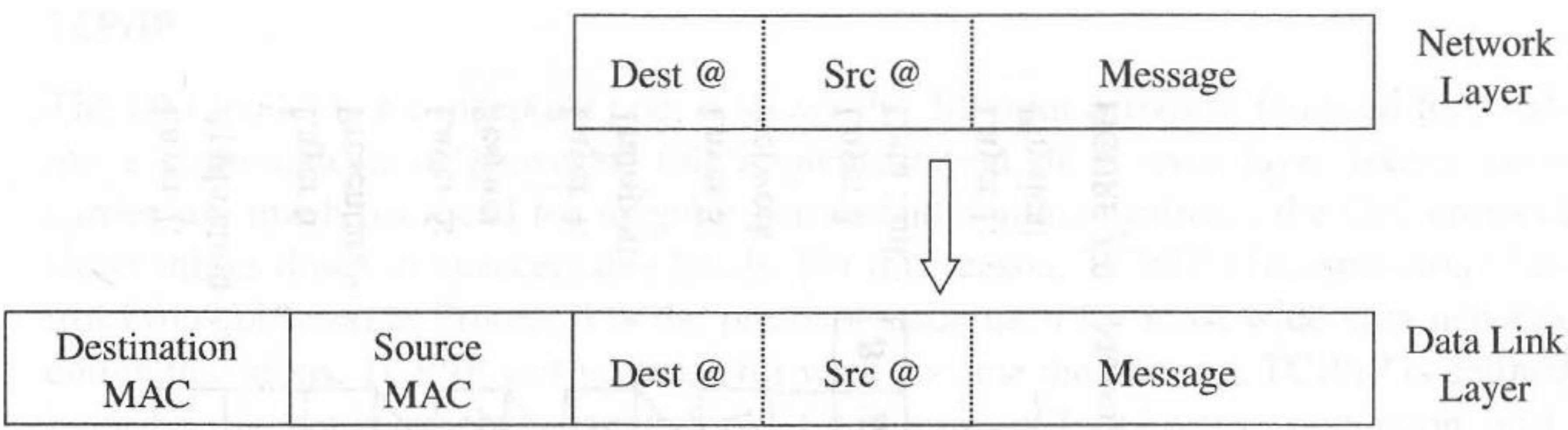
Addressing

- The network layer structured with destination address, source address, and data is called a packet.

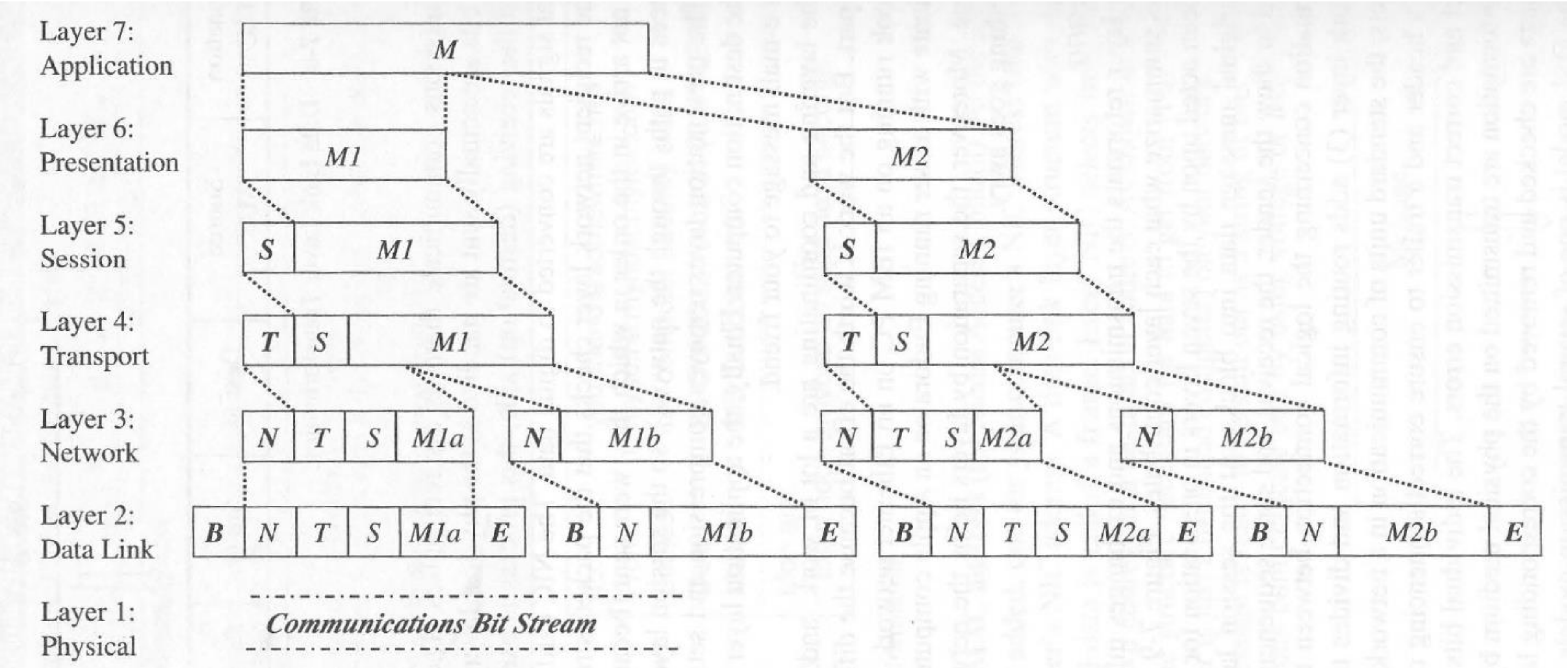


Addressing

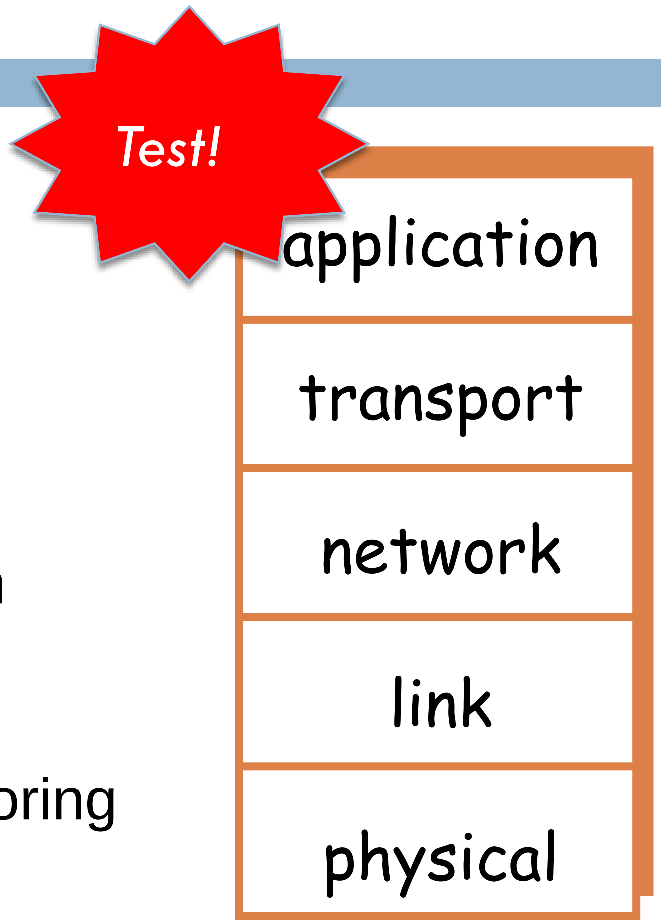
- Every computer connected to a network has a network interface card (NIC) with a unique physical address, called a MAC address(for Media Access Control)
- At the data link level, two more headers are added, one for your computer's NIC address (the source MAC), one for your router's NIC address → frame



Message Prepared for Transmission

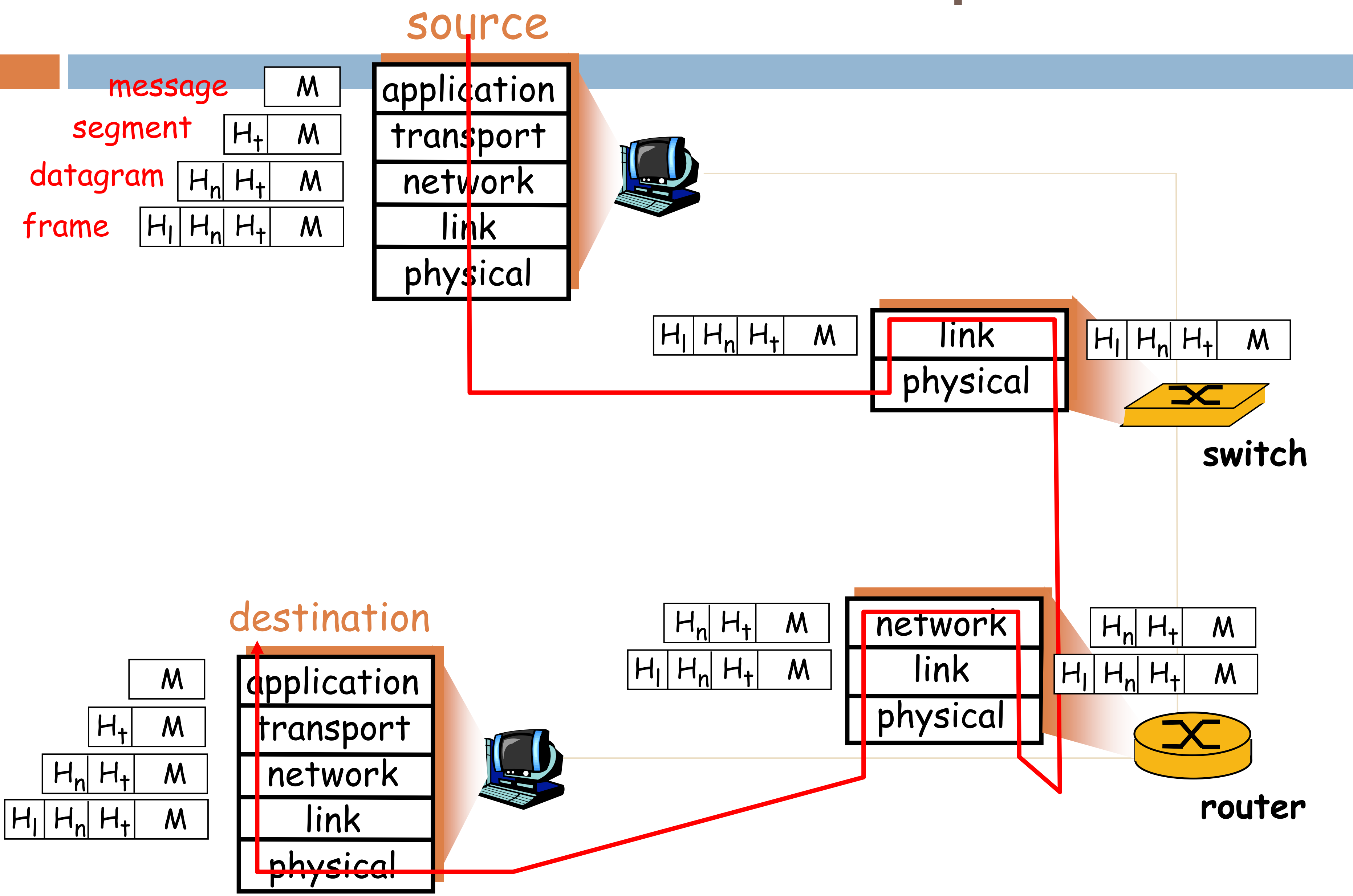


Internet protocol stack



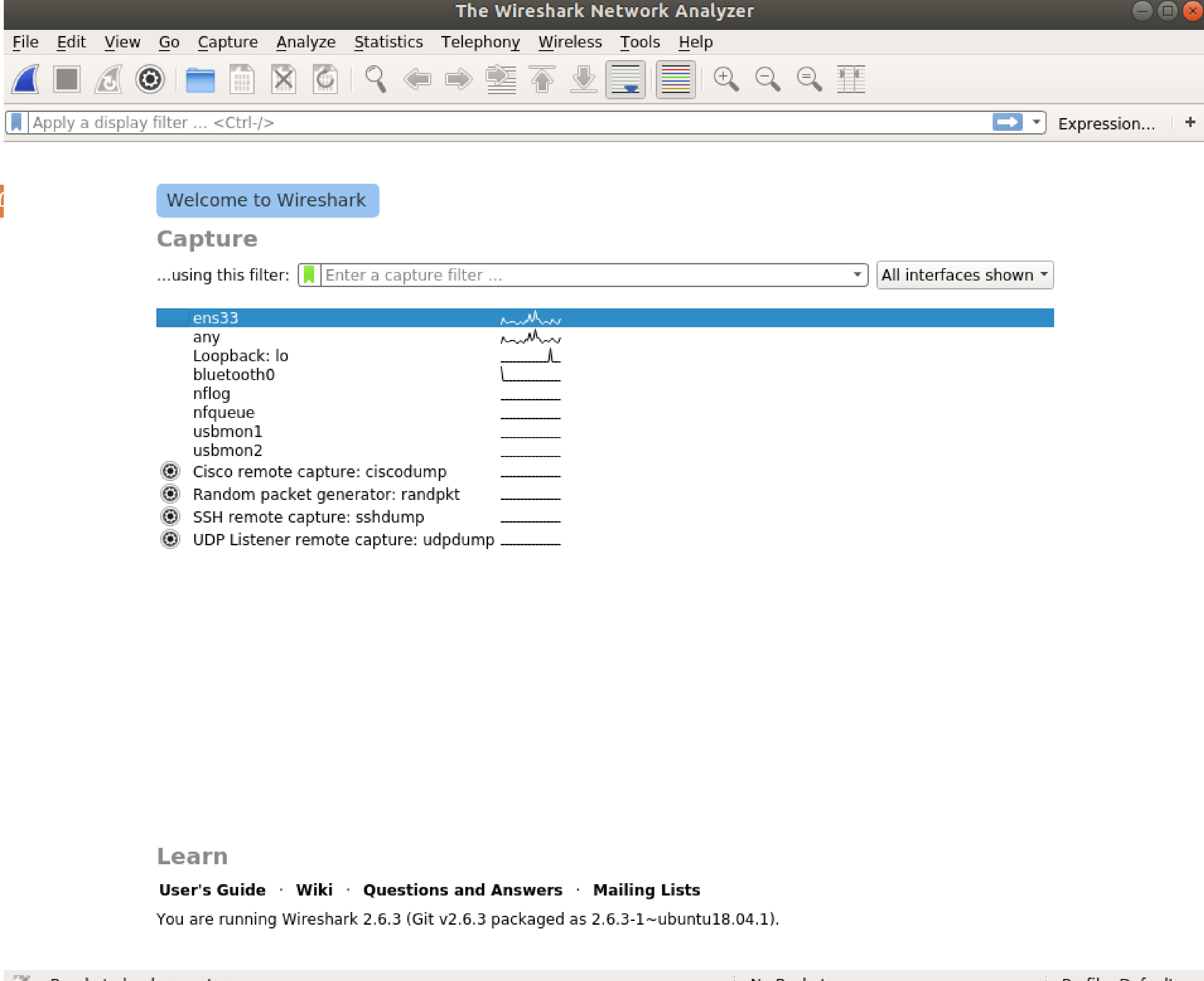
- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: process-to-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - PPP, Ethernet
- Physical: bits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

Encapsulation



Install Wireshark

- Install Wireshark
  - sudo apt-get update
  - sudo apt-get upgrade
  - sudo add-apt-repository ppa:wireshark-dev/stable
  - sudo apt-get update
  - sudo apt-get install wireshark
- If you failed installing or has older version
  - sudo apt-get remove --autoremove wireshark
- To execute wireshark
  - sudo wireshark &


The Wireshark Network Analyzer
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
Expression...
+
Welcome to Wireshark
Capture
...using this filter:
Enter a capture filter ...
All interfaces shown
ens33
any
Loopback: lo
bluetooth0
nflog
nfqueue
usbmon1
usbmon2
Cisco remote capture: ciscodump
Random packet generator: randpkt
SSH remote capture: sshdump
UDP Listener remote capture: udpdump
Learn
User's Guide · Wiki · Questions and Answers · Mailing Lists
You are running Wireshark 2.6.3 (Git v2.6.3 packaged as 2.6.3-1~ubuntu18.04.1).
Ready to load or capture
No Packets
Profile: Default

Group Wireshark Exercise

- Capture packets for a minute
- While capturing, browse http://google.com
- Stop capture.
- Identify the location of the following
  - User Data
  - TCP
  - IP
  - Ethernet

History

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 demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

Robert Taylor - ARPAnet

Early computing pioneer Robert Taylor dies

The technology world just lost one of its most prominent innovators. Robert Taylor, best known as the mastermind of ARPAnet (the internet's precursor), has died at 85. As the director of the US military's Advanced Research Projects Agency from 1965 until 1970, he helped pioneer the concept behind shared networks -- he was frustrated with constantly switching terminals and wanted to access multiple networks from one system. While a lot of the credit goes to his team for implementing ARPAnet, he both pushed hard for the project and wrote a legendary 1968 essay that foretold the internet's future: a vast, decentralized grid of connected devices that would reshape communication at just about every level.
This wasn't Taylor's only influential role. He went on to Xerox's fabled Palo Alto Research Center, which he oversaw (first as associate manager and then as full manager) during one of its most influential periods. PARC broke ground on Ethernet

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70'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

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

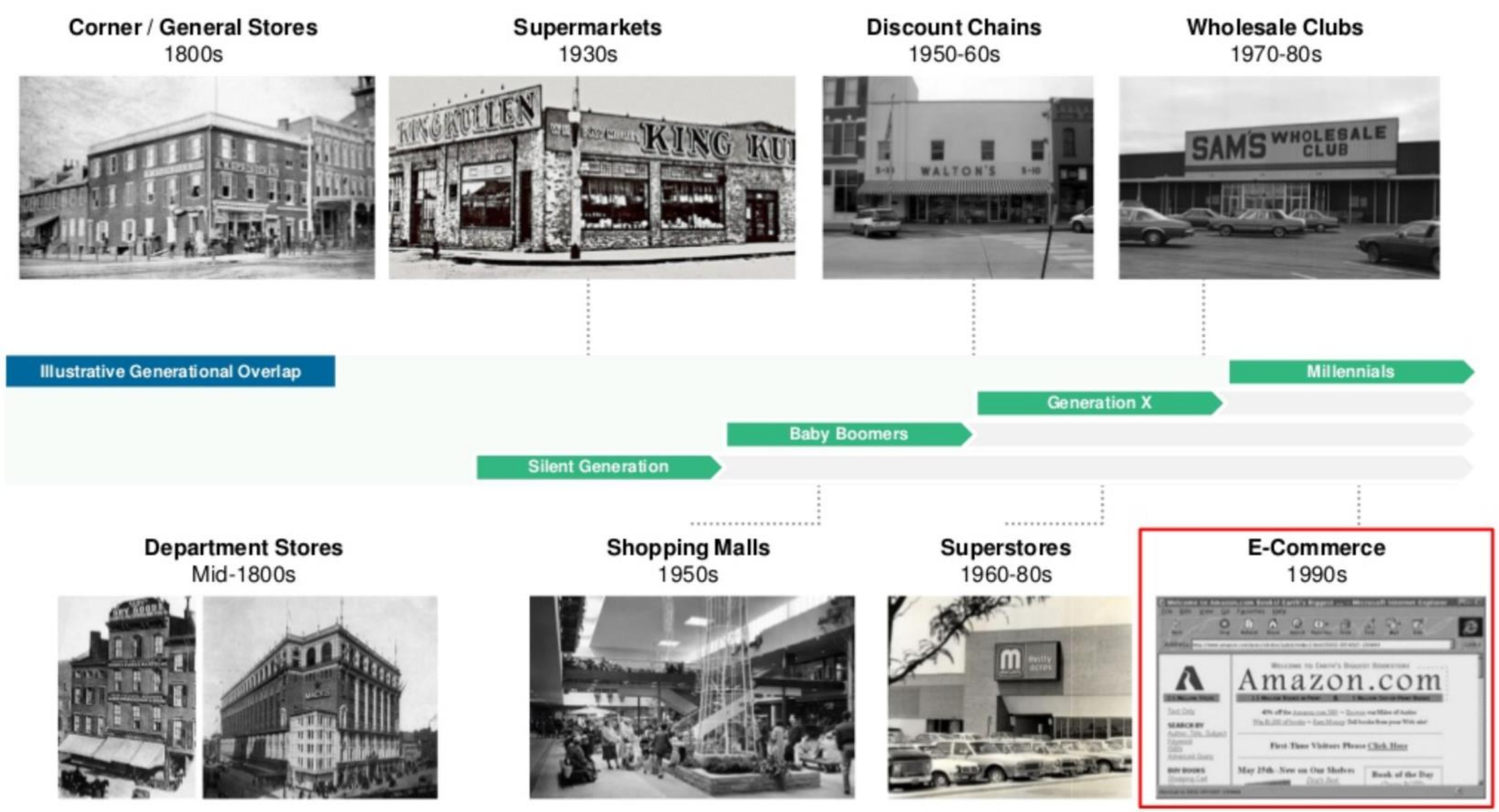
- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - **HTML, HTTP: Berners-Lee**
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

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

Evolution of Commerce Over Past ~2 Centuries, USA = Stores → More Stores → Malls → E-Commerce



Internet History

New / Emerging Retailers Optimize for Generational Change =
J.C. Penney → Meijer → Walmart → Costco → Amazon → Casper

Retail Companies Founded by Decade (Illustrative Example), USA, 1900 – 2015

Sears Files Bankruptcy

- Sears, who sells everything to anyone files bankruptcy!

Sears, the store that changed America, declares bankruptcy

By Chris Isidore, CNN Business

Updated 12:58 PM ET, Mon October 15, 2018

Introduction: Summary

Covered a "ton" of material!

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

You now have:

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