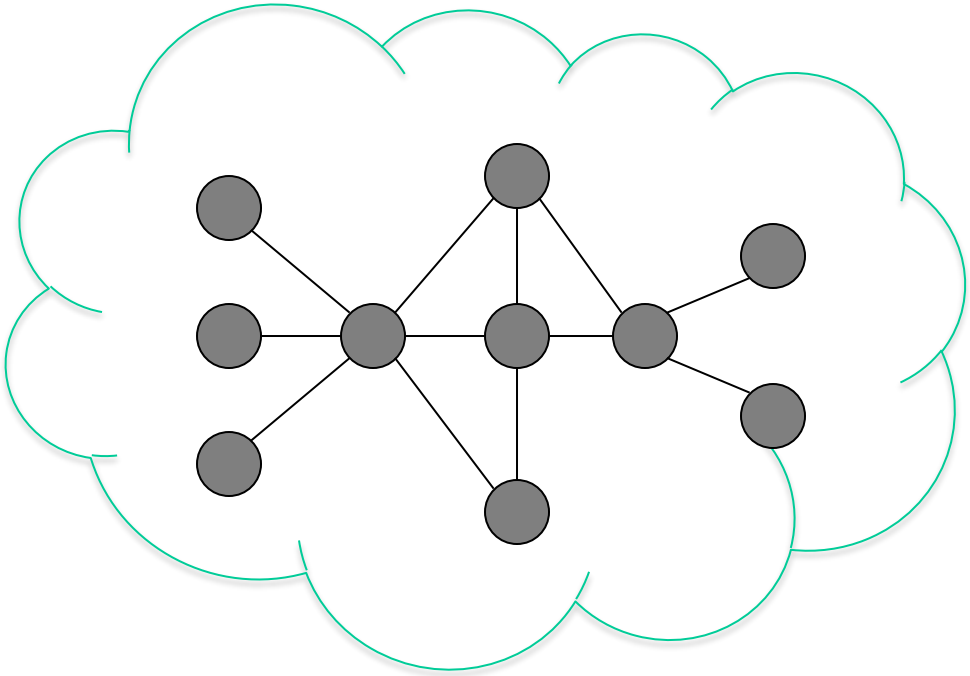
CE 352: Computer Networks

Salem Al-Agtash

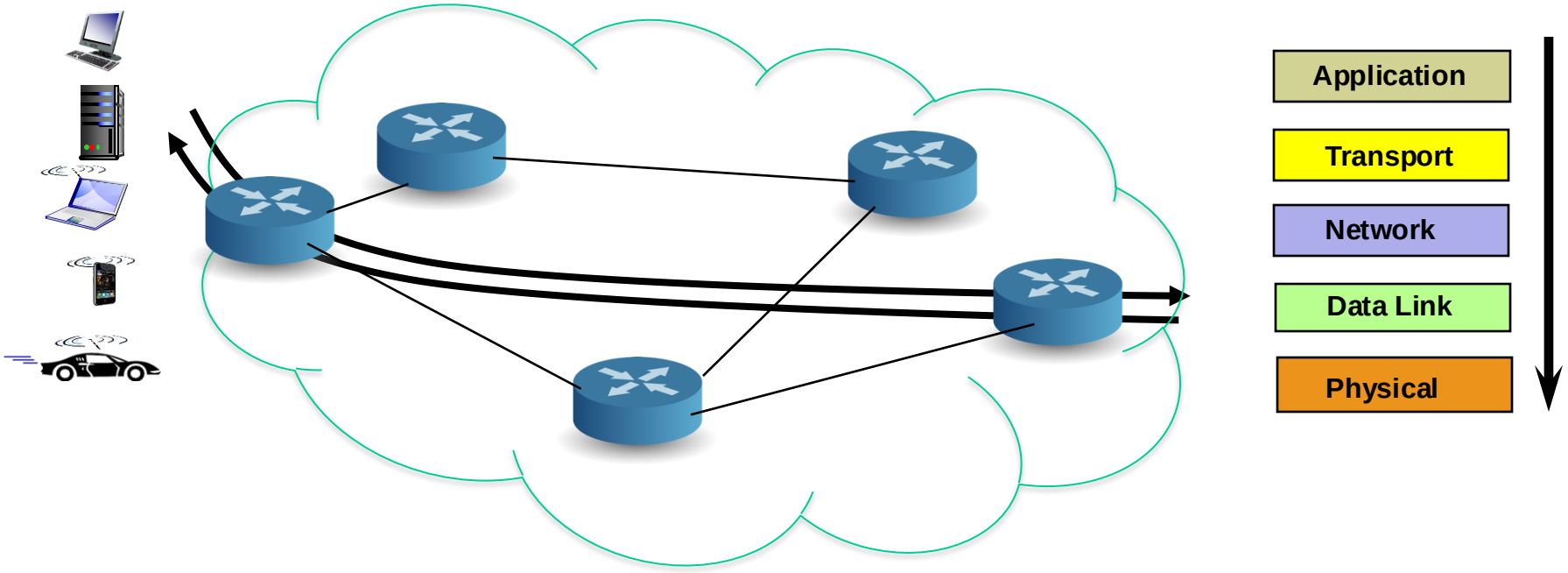
A network: Interconnected nodes

- A network is a system of nodes interlinked with each other designed and built with a purpose to transmit data/ information between nodes.
- Types of networks:
  - Computer (mesh, star..)
  - Internet (LAN, WAN)
  - Cellular (broad band)
  - Telephone
  - Wireless Sensor
  - Optical
  - etc..



Internet: Interconnected Networks

- A complex system that ties together more than 20,000 Internet Service Provide (ISP) networks that are federated (interoperable)
- The "Internet Protocol" – IP represents the common Interface for the interconnection
- Two main factors lead to success:
  - Ease of interoperability contributed to evolutions of applications and services
  - Economics and real-world trust drove the operation of reliable network topology



Scaling up

- 4.88 billion Internet Users (62% of world population)
  - 2.89 billion Facebook users
    - 5.6 billion Google searches per day
- 2.4 billion Emails sent per sec
  - 5 Billion YouTube videos viewed per day
    - 1.3 Trillion web pages

……Ubiquitous Computing…

….. Transformation…..

Evolutionary and practical design

Modularity Security Performance Protection Portability

Growing diversity

Transmission – Bandwidth/Capacity: Kbps, Mbps, Gbps, Tbps

- Optical, Copper, Satellite, Wireless

Devices [smart tendency]

- Routers, Switches, Servers, Computers, Phones, Appliances, Sensors

Applications [peer-to-peer, client-server]

- Cloud, Browsers, Office, Google, Facebook, YouTube, Twitter, Zoom, Canvas

Users [active, passive, malicious]

- Operators, Governments, Businesses, Schools, Household, Health, Gaming, …

… Internet of Things …

Key principles

- The Internet builds on evolutionary and practical design
- Numerous problems yet to solve:
  - IP hides federation, network authentication, complexity, painful upgrades
- Changing requirements
  - Mobility, reliability, interoperability…
- Physical limitations
  - speed of light ($3x10^8$ m/s)

Course Outcomes

- 1> Describe the Internet and the building blocks of computer networks
- 2> Describe services in the application layer, DNS, email, and the web, as well as client-server and peer-to-peer applications.
- 3> Write system calls and socket programming tools in Unix/Linux and C to build transport layer TCP/IP and UDP/IP reliable data transfer services
- 4> Explain the network layer in the context of both per-router and
- 5> Describe techniques for error control, flow control, ARP and MAC
- 6> Explain wireless networks (SNR, BER, 802.11 LAN, and cellular networks)
- 7> Explore computer network security, including cryptography
- 8> Describe sustainability and how the Internet impacts social, economic, and environmental systems

Course Topics

Concepts

- The Internet
- Packets, circuits, bandwidth, delay, loss
- Endpoints and networks
- Technologies: Ethernet, Wireless
- Security: Cryptography, IDS, IPSec

Layers

- Applications: HTTP, FTP, DNS
- Transport: TCP, UDP
- Network: IP, DV/LS routing, OSPF, BGP
- Data link: ARP, VLAN, MPLS, DHCP
- Wireless and mobile networks

Learning about Computer Networks is not only

.....important and relevant but also FUN.....

Because….

- Key infrastructure that supports distributed operation and communication
- Central to most technology companies and inventions of a global nature
- Big business: Technology, Finance, Stock, Education, Health, News, Data, …

Instructor: Salem Al-Agtash

- Ph.D. in Electrical Engineering from CU Boulder in 1998
- 26 years of experience in teaching, research, and consulting
- Relevant experience
  - Campus networks, High speed networks, e-Infrastructures, interoperable platform

Textbook:

- J. Kurose and K. Ross, *Computer Networking – A Top Down Approach Featuring the Internet*, Pearson Addison-Wesley, 8th Edition, 2021

Course material and website: https://canvas.instructure.com/courses/10364217

Class participation.....

.....is highly encouraged!

Honor code

- All students taking courses agree, individually and collectively, that they will neither give nor receive unpermitted aid in examinations, assignments, or other coursework that is to be used by the instructor as a basis for grading.

The Internet, network structure, packet and circuit switching

CE 352: Computer Networks

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Lecture 1

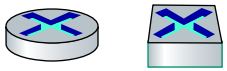
Main topics

- The Internet, Network Structure
- Network edge:
  - Hosts, clients, servers and devices connecting through home, enterprise, wireless, and datacenter access networks
- Network access: physical media
  - guided (copper, fiber)
  - unguided (wireless, microwave, satellite)
- Network core: switches, devices
  - ISP routing,
  - packet switching, circuit switching

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

- *hosts* = *end systems*
- running *network apps* at Internet's "edge"



Packet switches: forward packets (chunks of data)

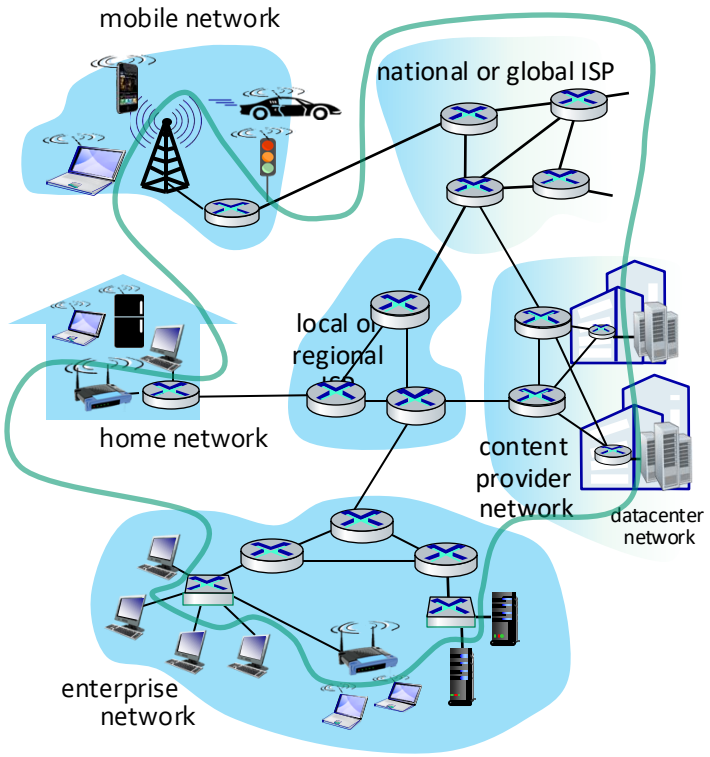
- *routers*, *switches*

Communication links

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

- collection of devices, routers, links: managed by an organization



Internet-connected devices

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

cars

Security Camera

Slingbox: remote control cable TV

Web-enabled toaster + weather forecaster

AR devices

scooters

Internet phones

Gaming devices

sensorized, bed mattress

Fitbit

Others?

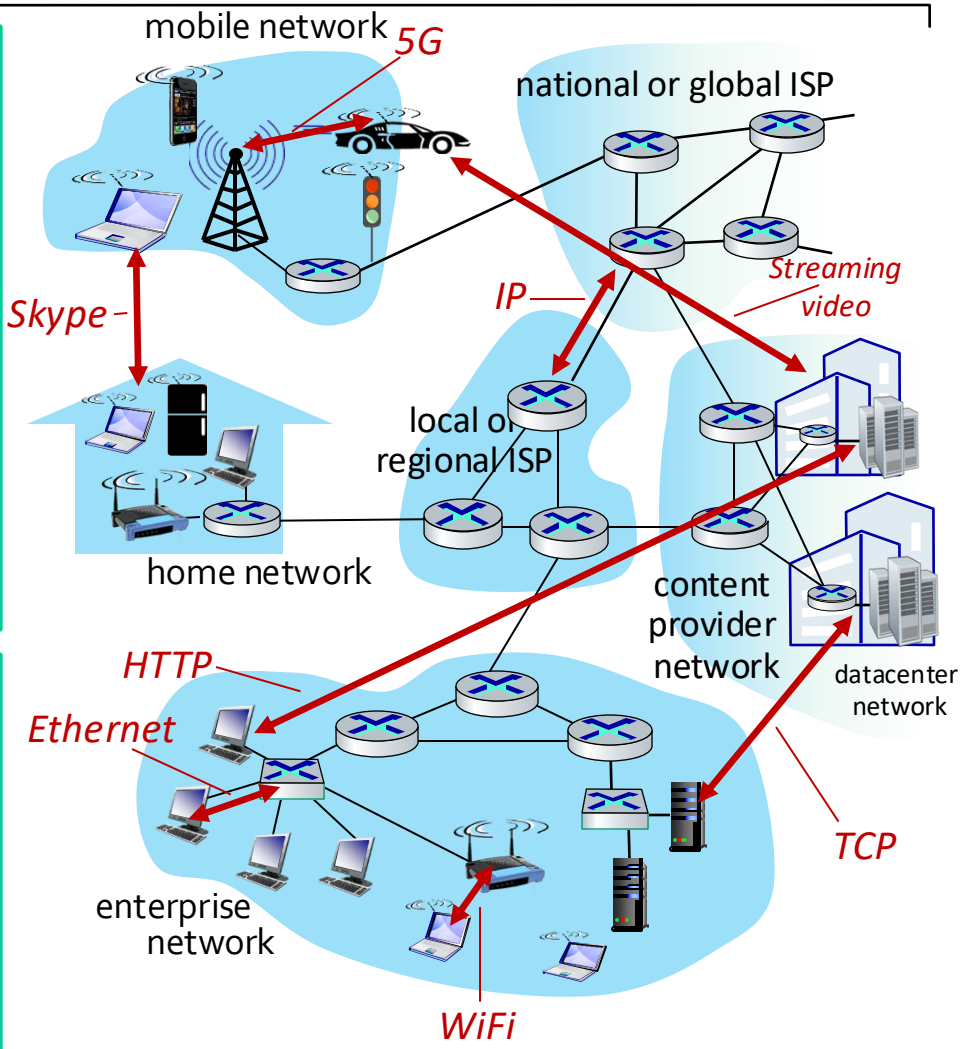
The Internet

General view:

- Internet: "network of networks"
  - Interconnected ISPs
- Protocols: control sending, receiving of messages e.g., TCP, IP, HTTP, Skype, 802.11
- Standards: RFC: Request for comments, IETF: Internet Engineering Task Force

Service view:

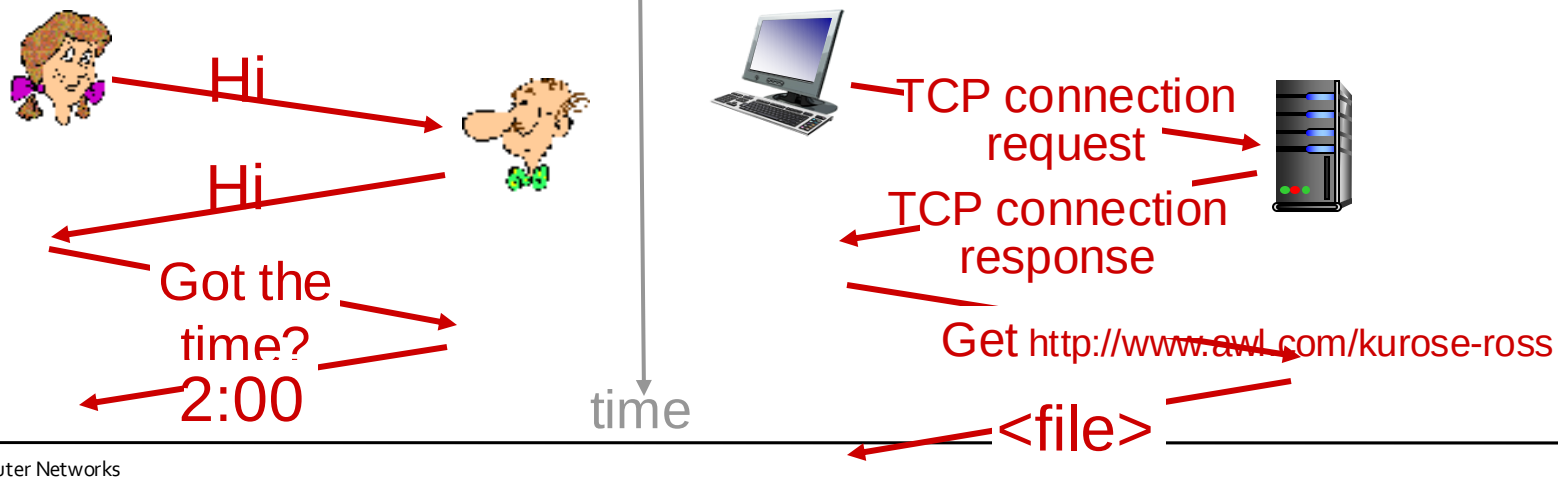
- Infrastructure that provides services to applications: Web, email, VoIP
- Provides programming interface to applications



Protocols

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

- Human protocols:
  - "what's the time?"… 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



Network structure

Network edge:

- hosts: clients, servers (data centers)

Access networks, physical media:

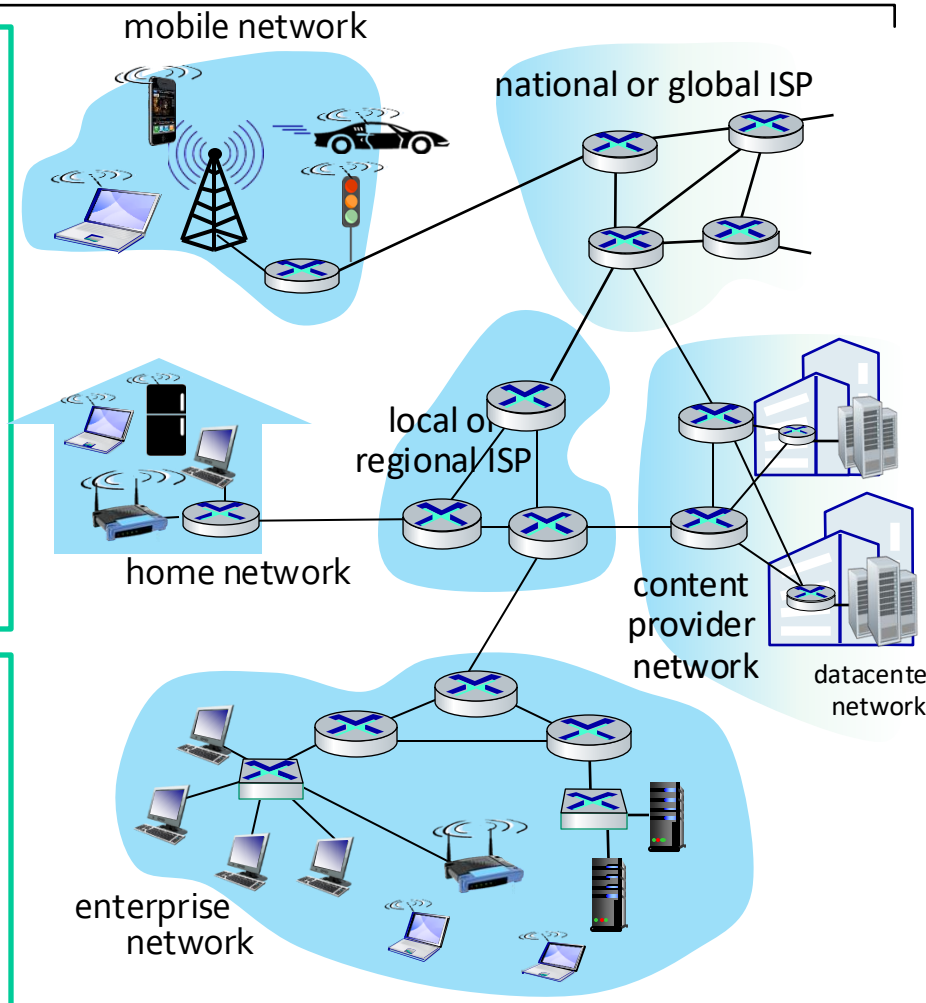
- wired, wireless communication links

Network core:

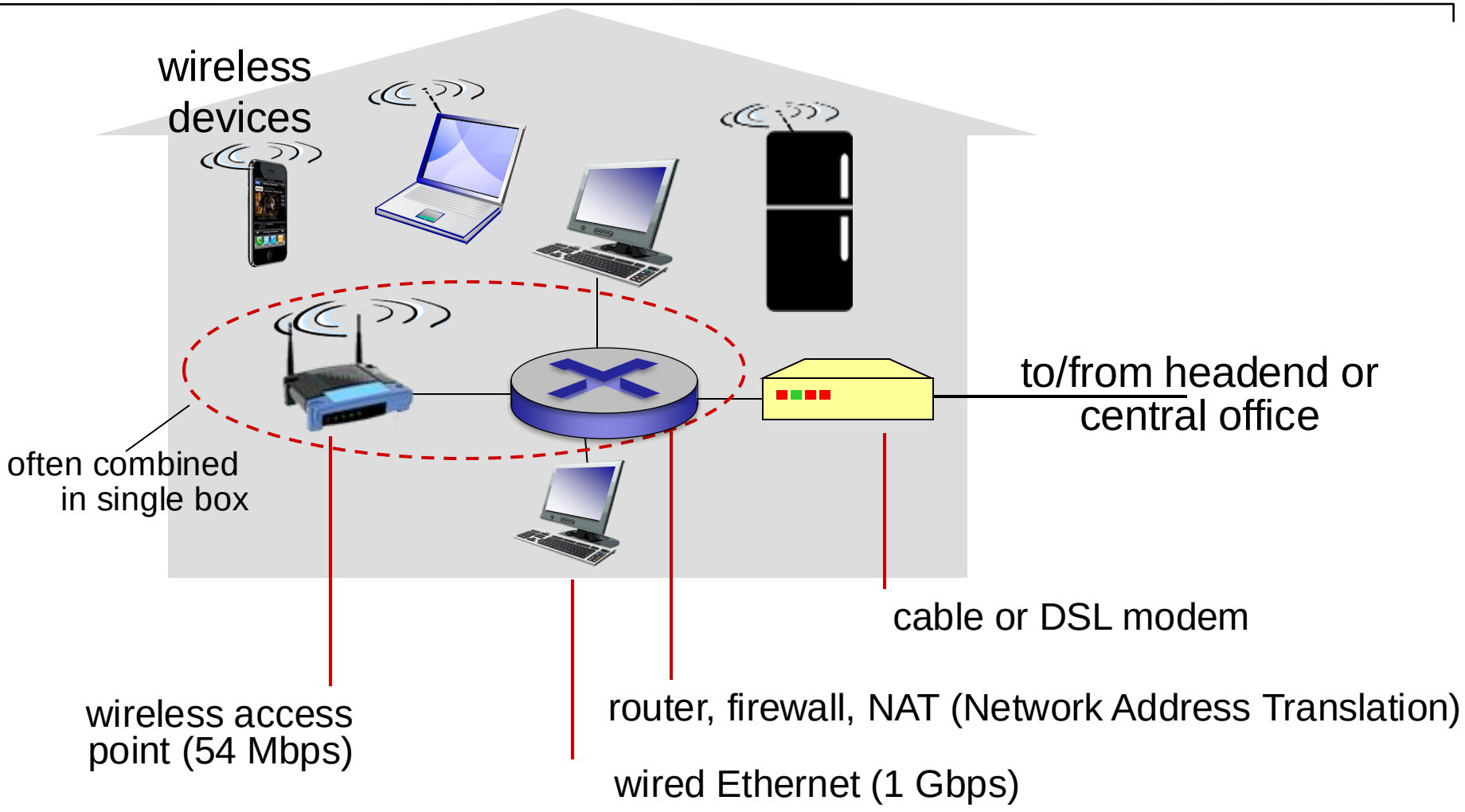
- interconnected routers
- network of networks

How to connect end systems to edge router? (bits per sec, shared/ dedicated)

- Home networks, enterprise networks (school, company), data center networks, mobile networks, content provider networks



Home network



Wireless network (Ethernet)

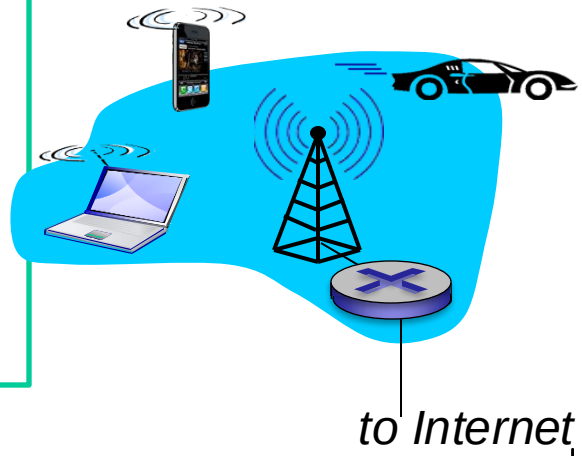
connects end system to router via base station aka "access point"

wireless LANs:

- within building (100 ft.)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

wide-area wireless access

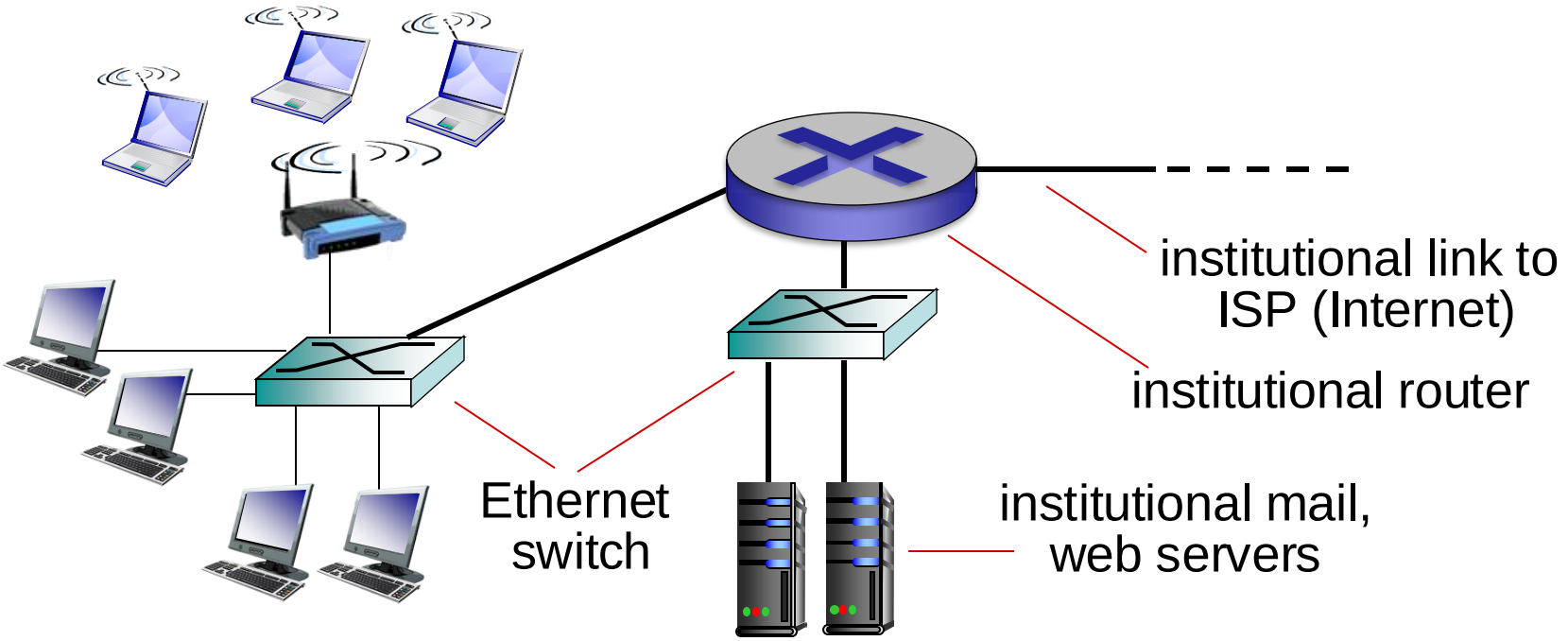
- provided by telco (cellular) operator, 10's km: 10's Mbps
- 4G, LTE, 5G



Enterprise network (Ethernet)

Typically used in companies, universities, etc.

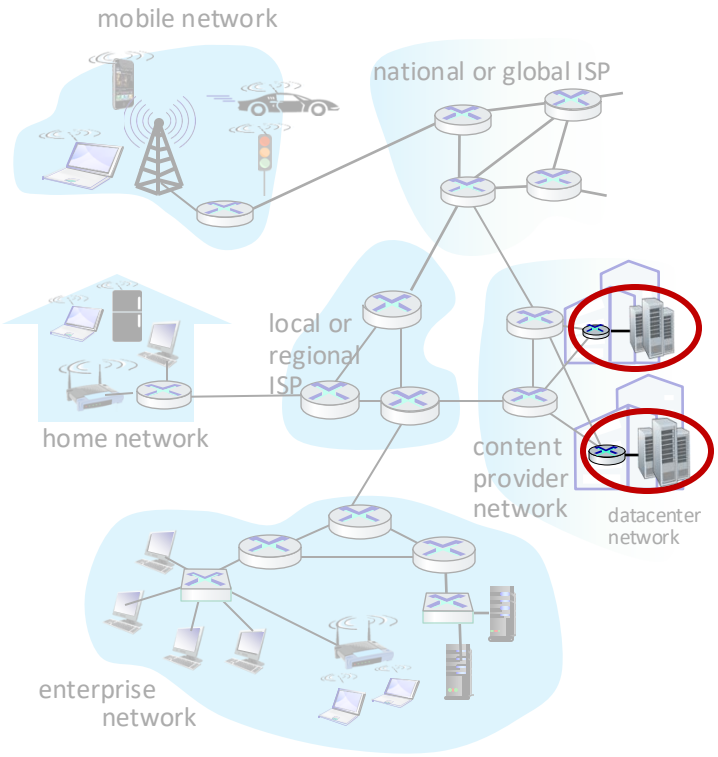
- mix of wired, wireless link technologies, connecting a mix of switches and routers
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps



Data center networks

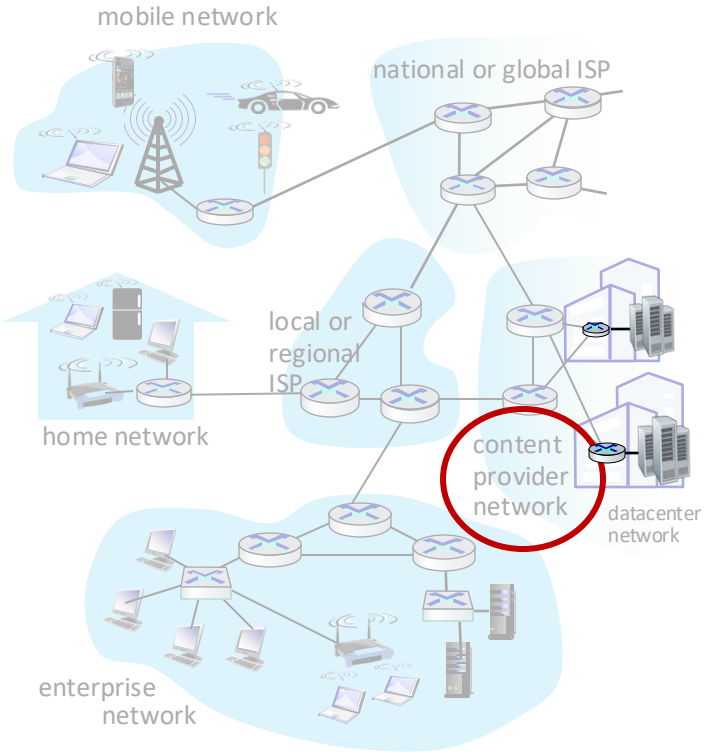
- High-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet

Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



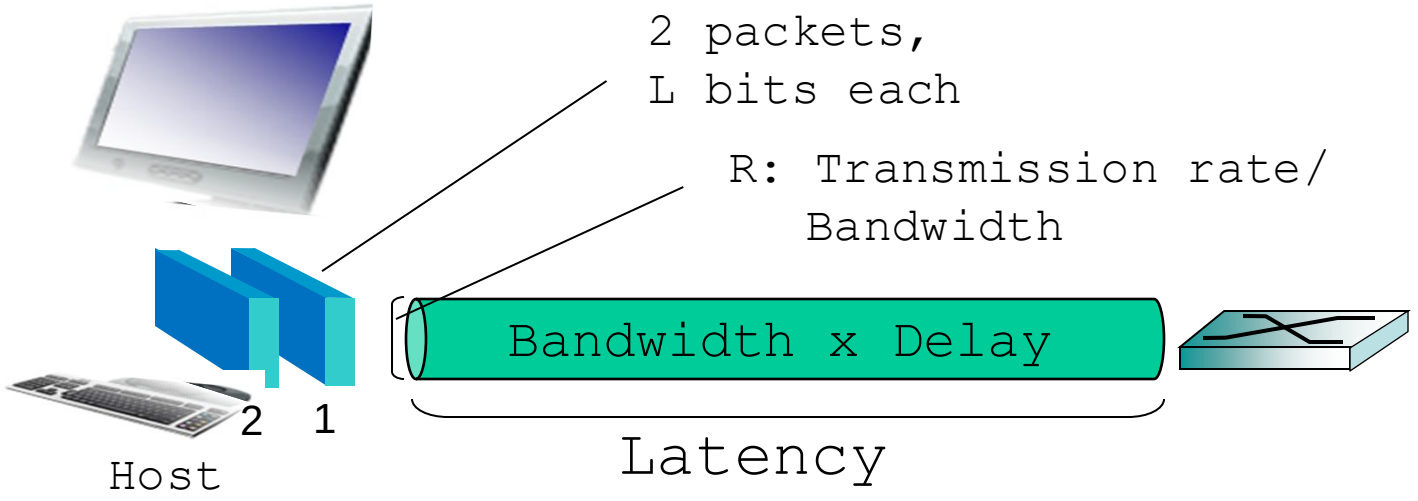
Content delivery networks

- Geographically distributed network of proxy servers and their data centers, e.g. eCommerce, Cloud computing, Social media, Streaming Media, …



Sending packets

Host takes application message, breaks into smaller chunks, known as *packets*, of length *L* bits, and transmits at *rate R*



Bandwidth (capacity): "width" of the link (physical media)

number of bits sent (or received) per unit time (bits/sec or bps) → transmission rate *R*

Latency (delay): "length" of the link

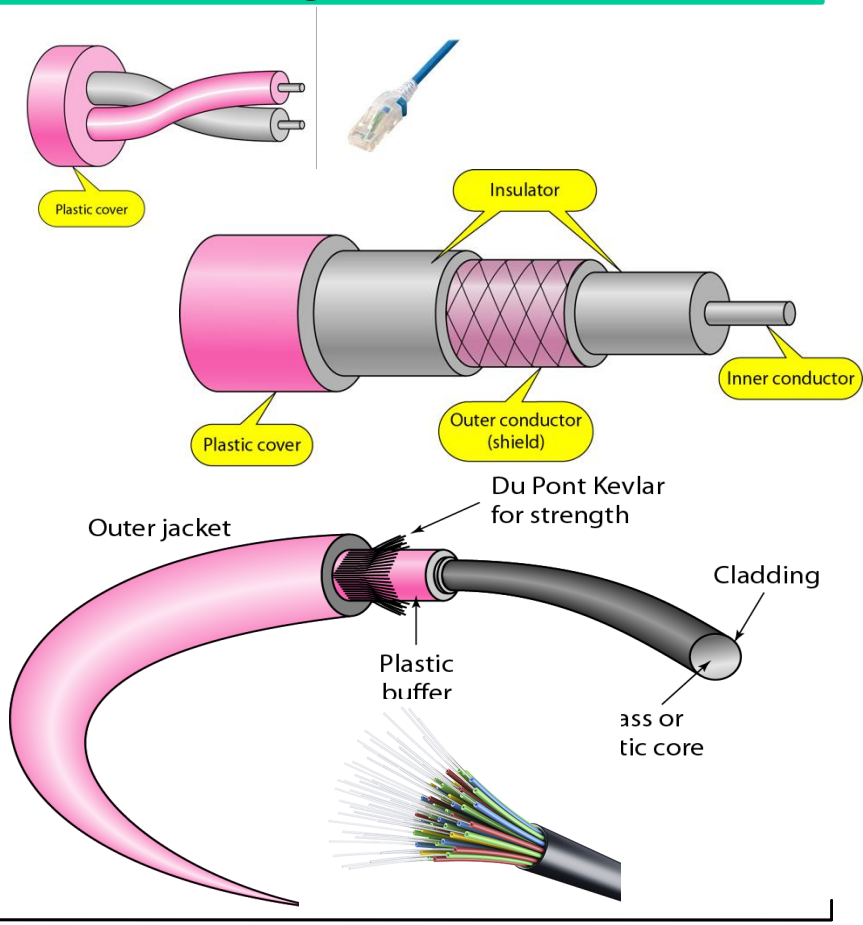
propagation time for data (L-bit packet) to travel along the link (seconds)

Physical media - guided

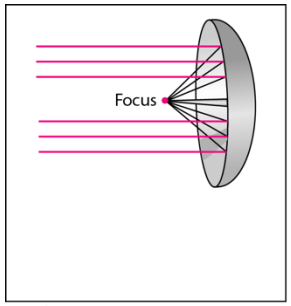
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver (e.g two hosts)

guided : signals propagate in solid media:

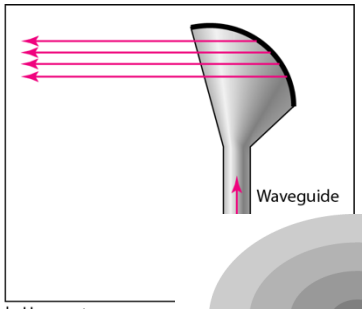
- Copper: *unshielded twisted pair (UTP)* two insulated copper wires; Category 5: 100 Mbps, 1 Gbps Ethernet; Category 6, 7: 10Gbps; *coaxial cable:* two concentric copper conductors bidirectional - Broadband: multiple channels on cable
- Fiber: glass fiber carrying light pulses, each pulse a bit - high-speed 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



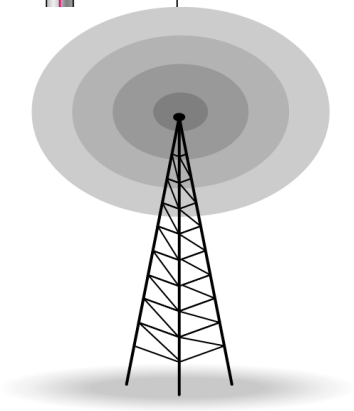
Physical media - unguided

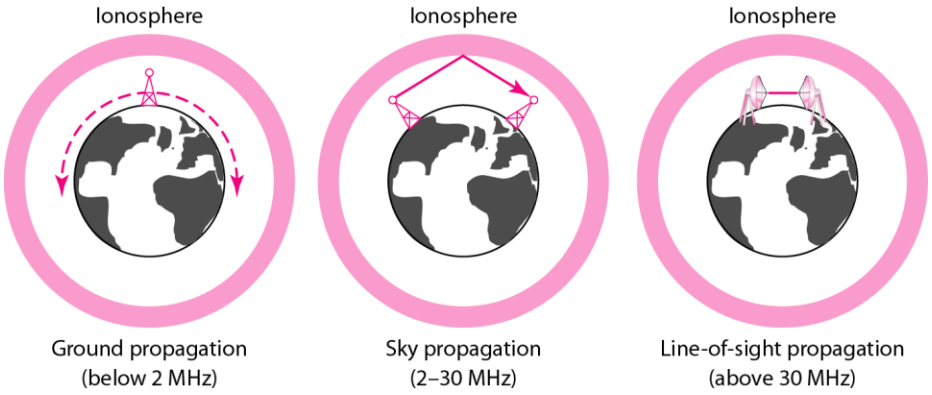


a. Dish antenna



b. Horn antenna



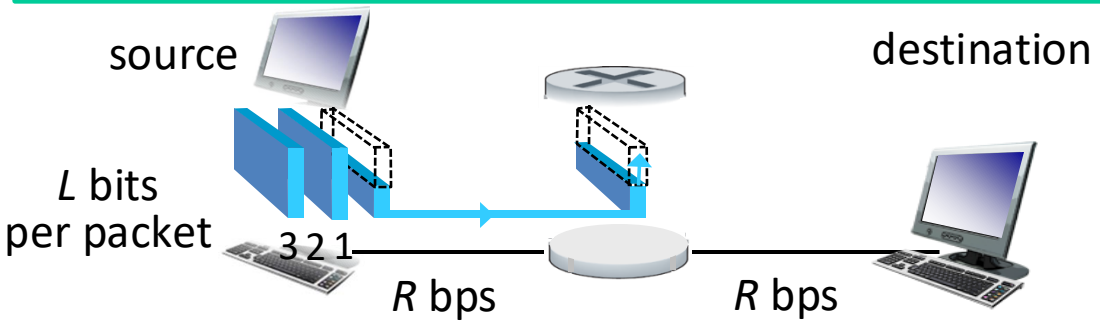


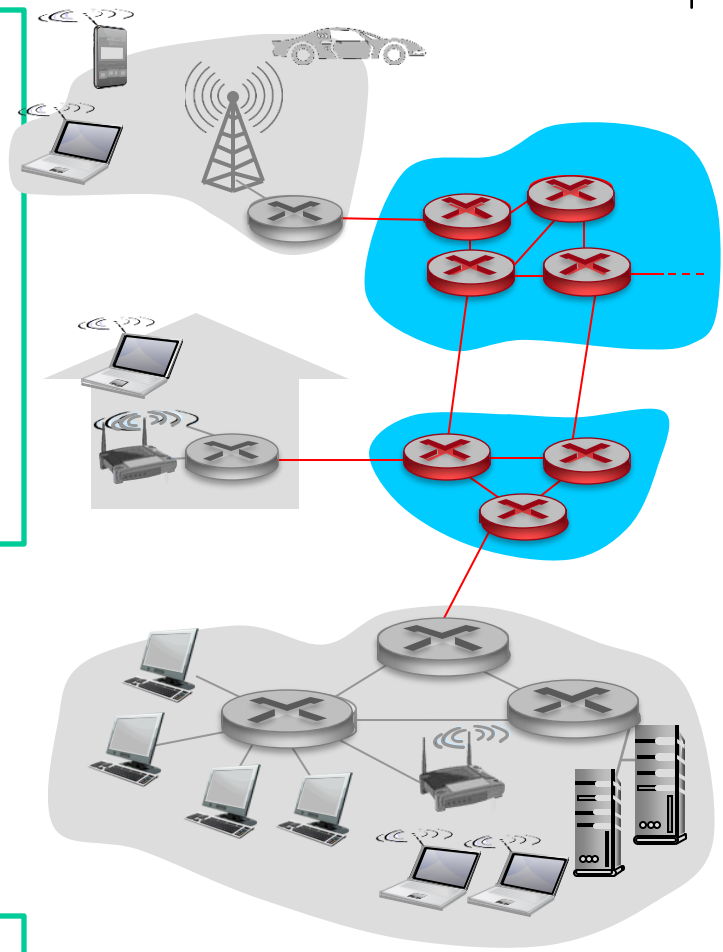
unguided: signals propagate freely, carried in electromagnetic spectrum: Bidirectional; propagation environment effects: reflection; obstruction by objects; interference

- terrestrial microwave: up to 45 Mbps channels
- LAN (e.g., WiFi) 54 Mbps
- wide-area (e.g., cellular), 4G, LTE, 5G cellular: ~ 100 Mbps
- Satellite: Kbps to 45Mbps channel (or multiple smaller channels); 270 msec end-end delay; geosynchronous versus low altitude

Network Core

- Nodes share link resources in a switched network:
  - Packet switching in the Internet
  - Circuit switching in the telephone network
- 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



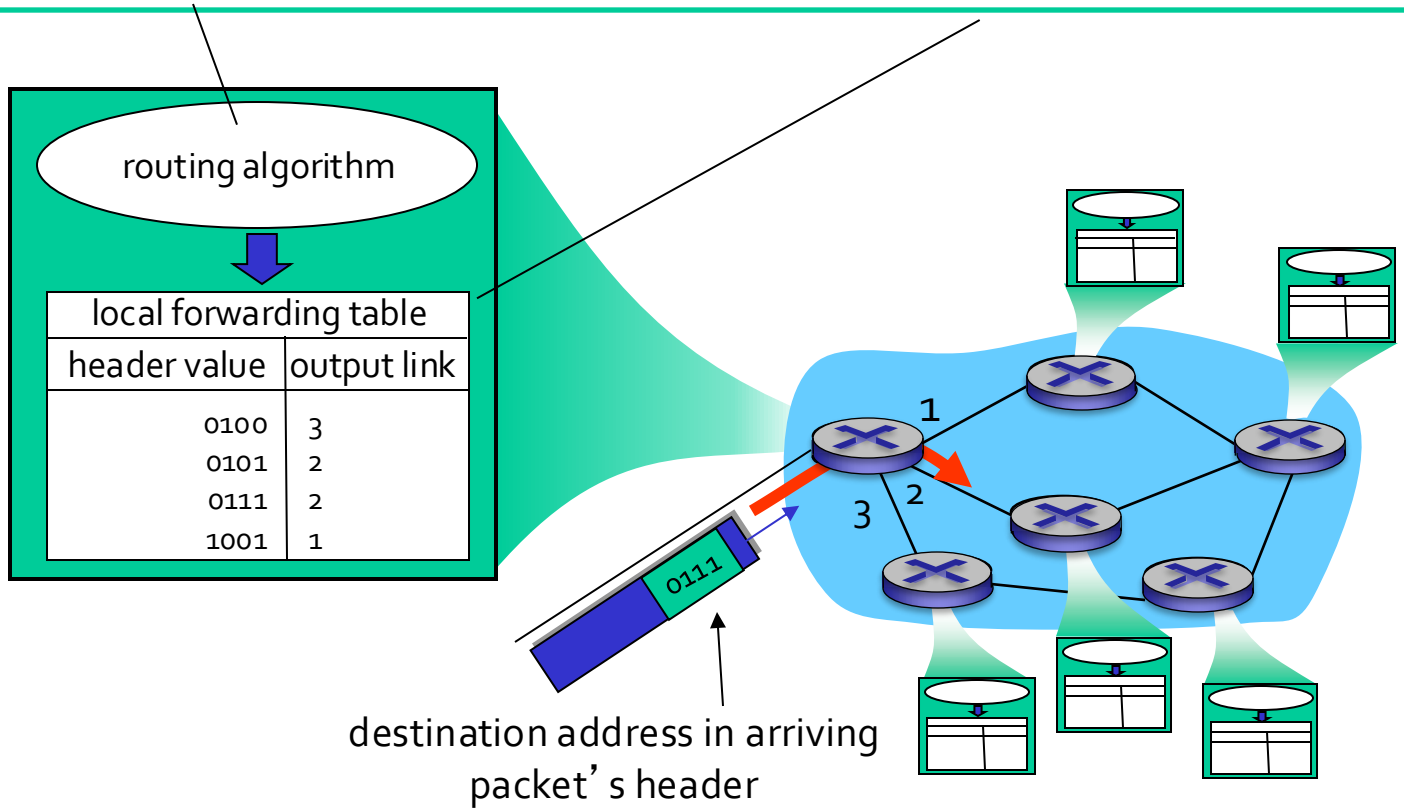


- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

Packet switching - key functions

routing: determines source-destination route taken by packets
- *routing algorithms*

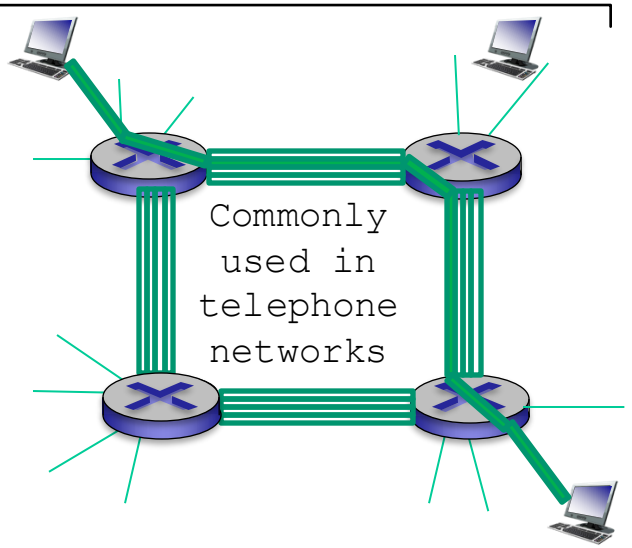
forwarding: move packets from router's input to appropriate router output

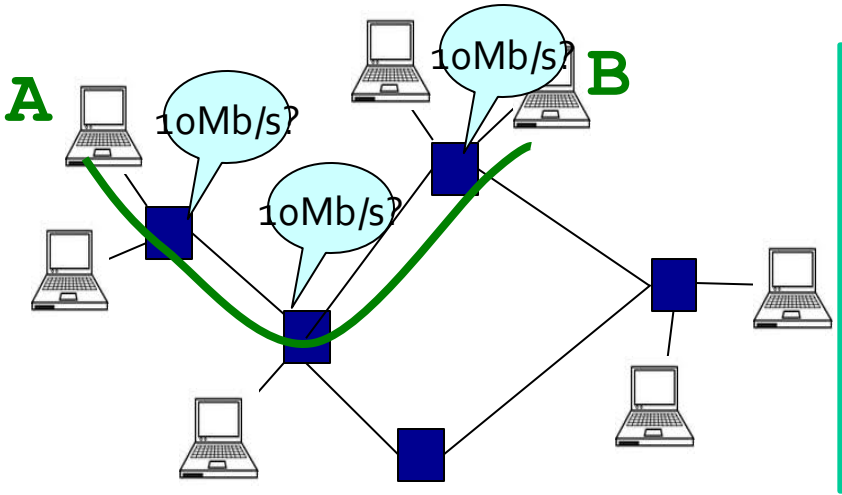


Circuit switching

end-to-end resources allocated to, reserved for "call" between source and destination

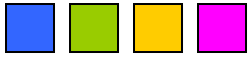
- e.g. each link has four circuits. call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*



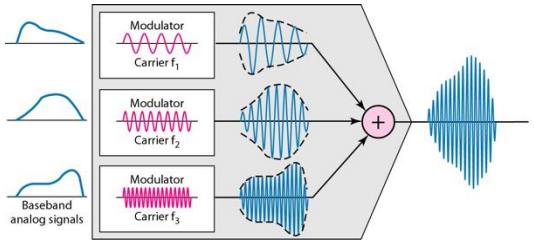


- source reserves network capacity along a path
  - Node A sends a reservation request
  - Interior switches establish a connection – "circuit"
  - A starts sending data
  - A sends a "teardown circuit" message

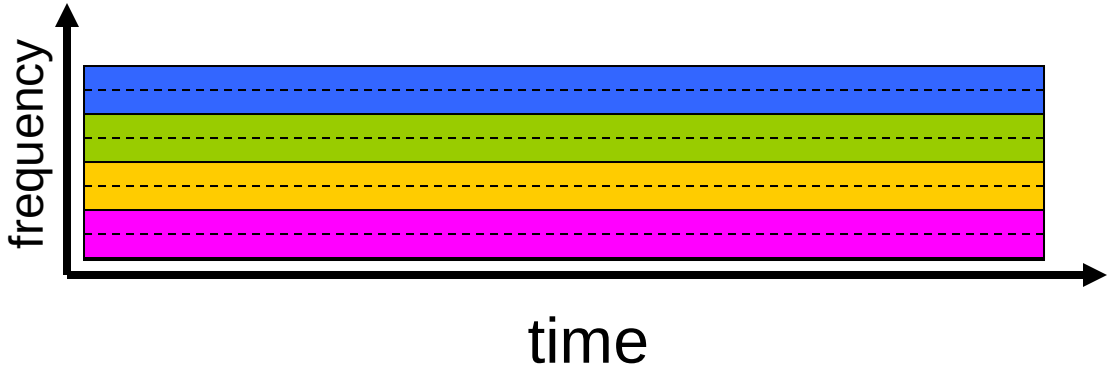
Circuit switching: FDM and TDM

4 users 

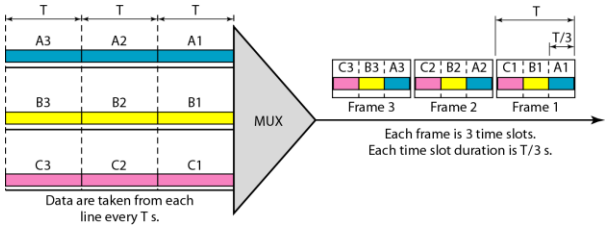
FDM: Frequency-division multiplexing



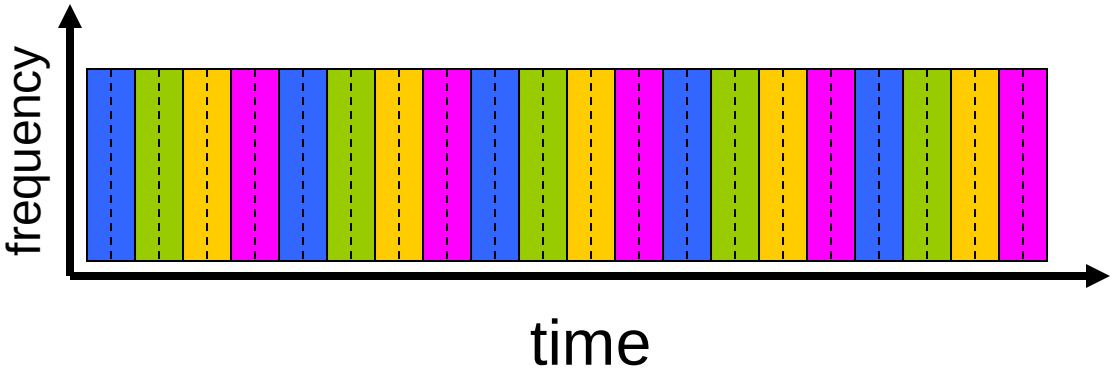
Each circuit allocated certain frequencies



TDM: Time – division multiplexing



Each circuit allocated certain time slots



Packet versus circuit switching

Packet switching

- Data is sent as chunks of packets
- Packets consist of "header" and "payload"
- Switches "forward" packets on headers
- Each packet travels independently
- No link resources are reserved in advance
- Allows more users to use the network
- Excessive congestion possible: packet delay and loss
- Protocols needed for reliable data transfer, congestion control

Circuit switching

- Guaranteed performance
- Fast transfer once circuit is established
- Wastes bandwidth if traffic is bursty
- Connection setup adds delay
- Recovery from failure is slow
- Designed for specific applications in the telephone network (e.g. ISDN: Integrated Service Digital Network)

Practice Exercise 1

- Demonstrate the use of Linux command – line programs
  - Commands: ls, more, mv, rm, mkdir, rmdir, cd, cp, chmod, who, ps, kill, ctrl+c, cmp, grep, cat, and man
  - Options: -a: all, -b: buffer, -c: command, -d: debug, -e: execute, -f: file, -l: list, -o: output, -u: user
  - Network commands: ping, hostname, netstat, ifconfig, traceroute, host, dig, arp
  - ping different hosts with different packet sizes,
    - identify packet loss
    - measure RTT
- To learn and demonstrate basic skills of C programming
  - int main(int argc, char *argv[])
  - File transfers using functions and system calls

Network Commands – Internet delays

- ping: sends ECHO_REQUEST datagram to a network host using ICMP protocol to elicit an ECHO_RESPONSE from the host or gateway. Type man ping to learn about all options.
- traceroute: displays the route packets trace to a network host using IP protocol "time to live". Type man tracerout to learn about all options.
- netstat: displays the contents of network interfaces, with – a option, the command displays the state of all active sockets (more to come on sockets as end points of communication). With – r option, the routing table is displayed. Type man netstat to learn about all options.
- ifconfig: configures network interface parameters. With – a option, the state of all interfaces are displayed. Other options are also used to assign a new IP address to an interface, to assign a new network mask for an interface, to disable an interface, and more. Type man ifconfig to learn about all options.
- hostname: displays and sets hostname of the system. Type man hostname to learn about all options.
- host/dig: performs DNS lookups.
- route: manipulates network routing tables.

http://www.traceroute.org

Summary

Today:

- CE 352: Computer Networks
- The Internet, Network Structure
- Network edge: home, enterprise, and wireless networks
- Network access: guided and unguided physical media
- Network core: routing, packet switching, circuit switching

Camino discussion:

- Reflection
- Exit ticket

Next time:

- read 1.4 of K&R (Delay, Loss, Throughput)
- follow on Canvas! Material, assignments, announcements

Any questions?