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COMP1047: Systems and Architecture

Dr. Fazl Ullah (Khan)

AY2023-24, Spring Semester

Week 6

Computer Networks Part. Fundamental Concepts

Introduction

- Most of the slides are based on the Books

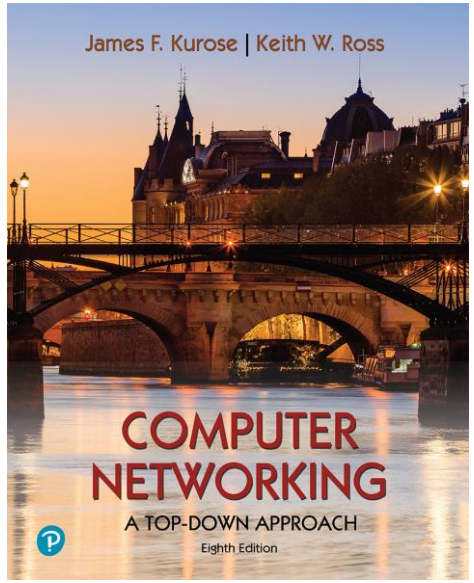
1. ***Computer Networking: A Top-Down Approach***

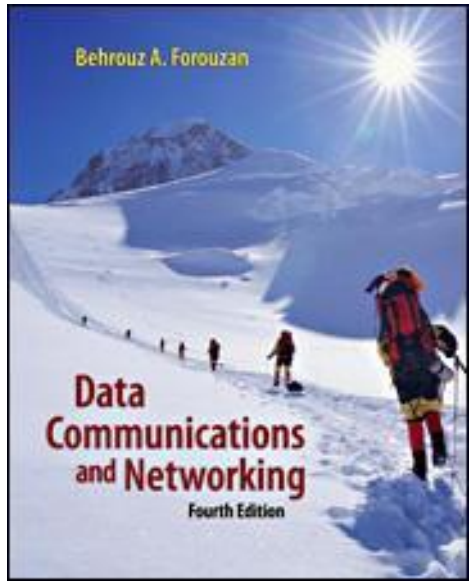
   8th edition by Jim Kurose, Keith Ross

and

2. ***Data Communication and Networking***

   4th e4dition by Behrouz A. Forouzan





Overview

Learning Outcomes:

- Learn the basic of networks and networking terminologies
- Understand the types of networks and how they are designed
- the basics of Internet

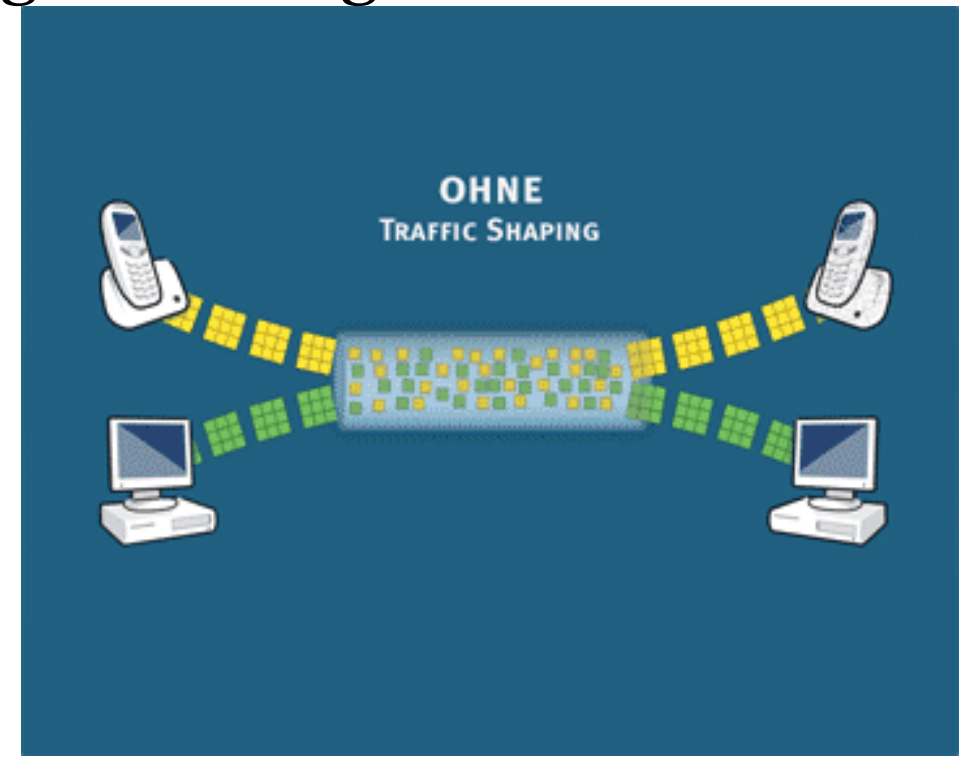
Overview/roadmap:

- Data and Communication
- Network and its types
- Topologies
- the Internet
- Protocol
- Network Edge
- Network Core

Our goal here is to paint a broad picture and set the context for the rest of the lectures, to see the forest through the trees.
We'll cover a lot of ground in this introductory chapter and discuss a lot of the pieces of a computer network, without losing sight of the big picture.

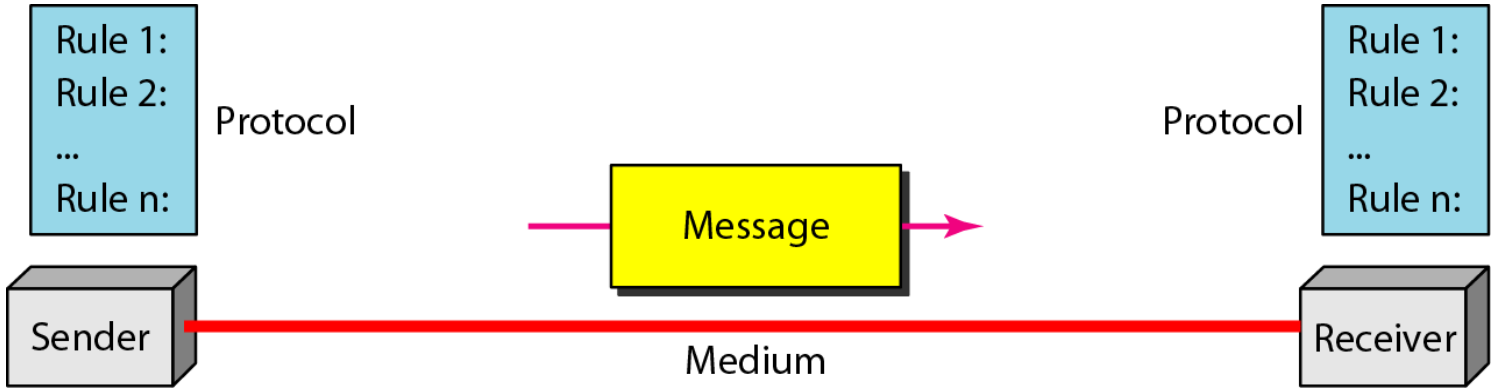
Data Communication

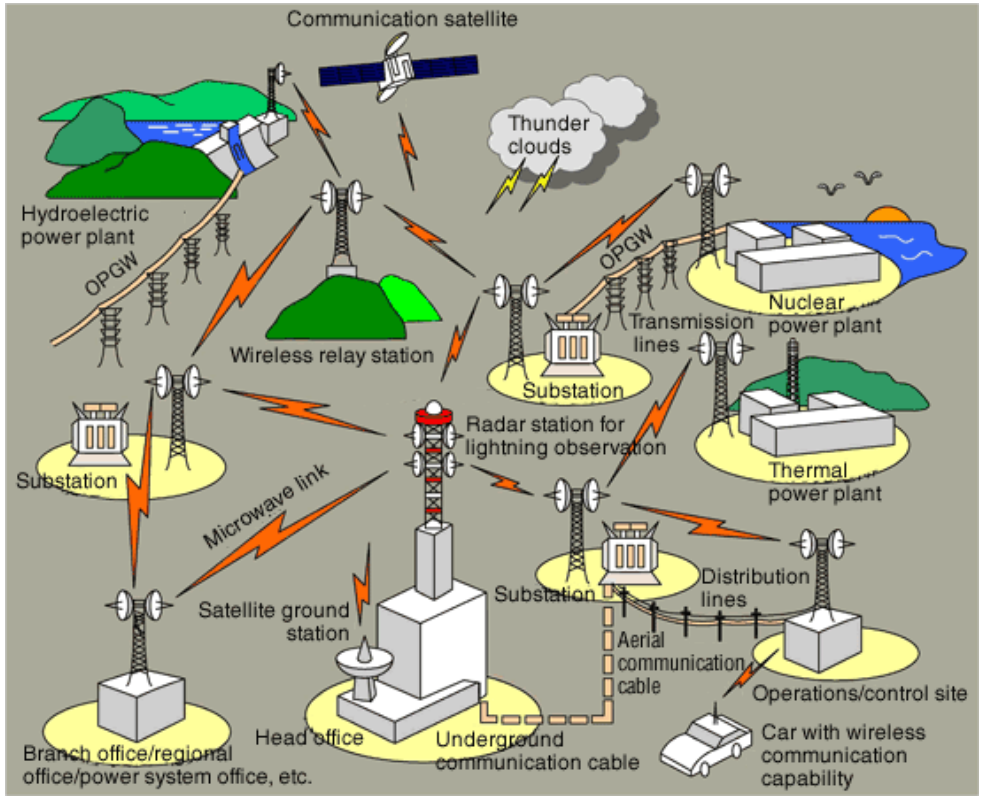
- *Data communications* are the exchange of data between two devices via some form of transmission medium.
- The word *data* refers to information presented in whatever form is agreed upon by the parties creating and using the data
- The term *telecommunication* means communication at a distance



Components of a Communication System

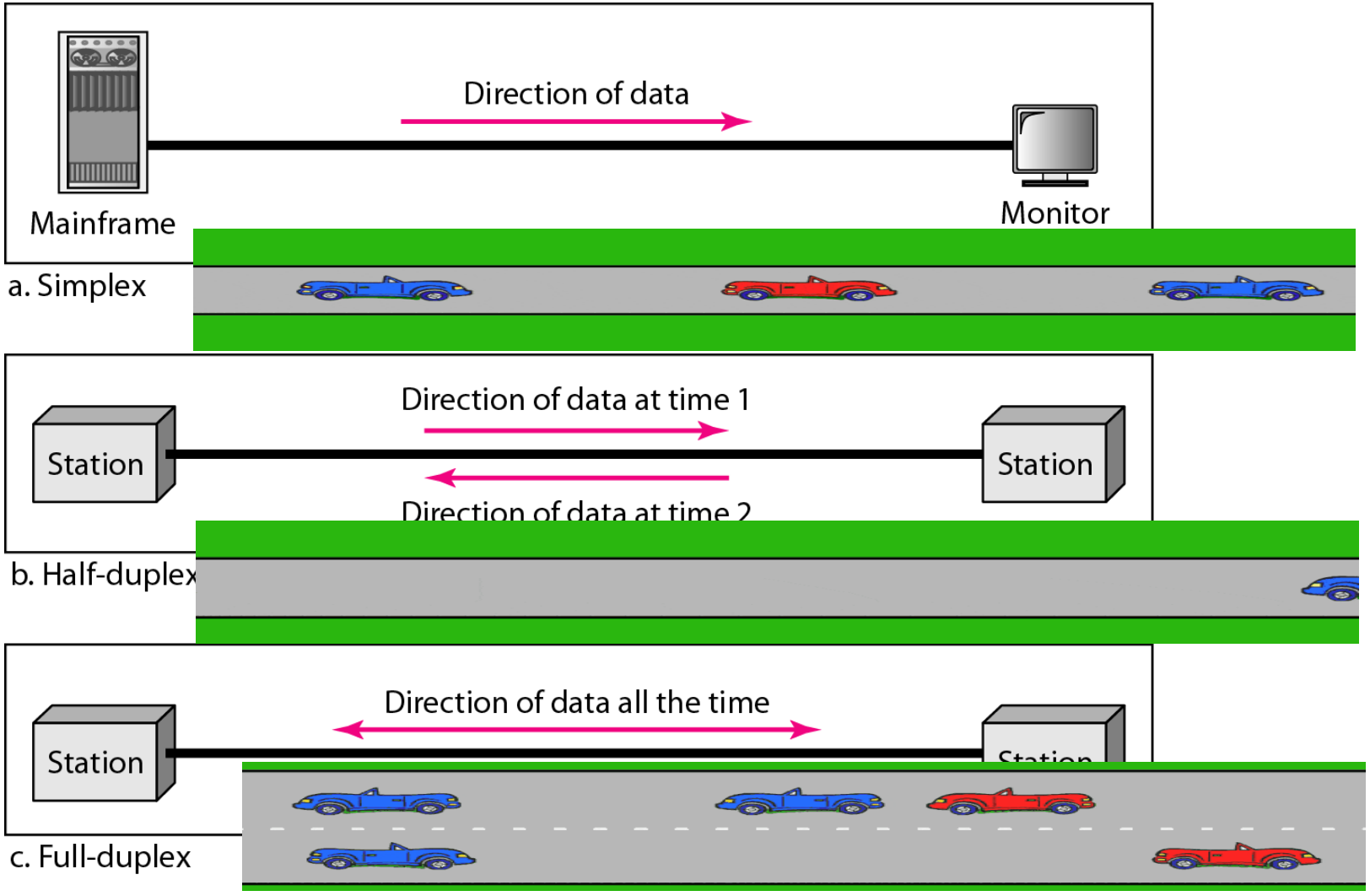
- *Sender: The node sending a message*
- *Receiver: The node receiving a message*
- *Medium: A channel through which message is transmitted*
- *Message: Any piece of data or information*
- *Protocol: The system of rules to communicate*





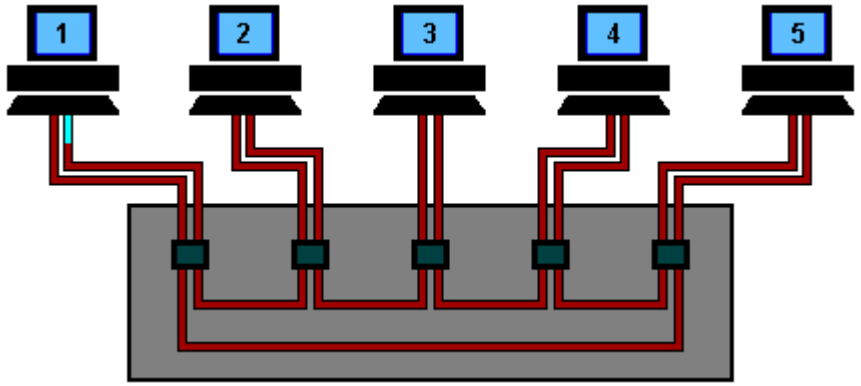
Data Flow

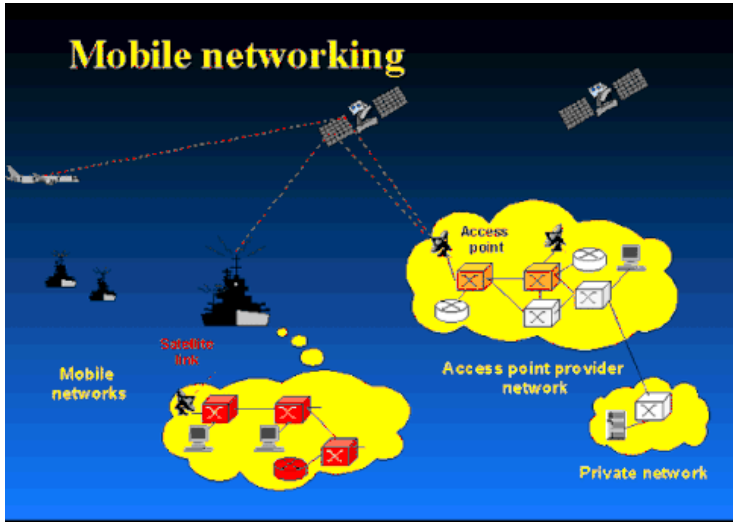
- *Data Flow: The route that data takes from sender to receiver*
- *Simplex:*
  - *Keyboard*
  - *Traditional Monitor*
- *Half-duplex:*
  - Walkie-Talkie
- *Full-duplex:*
  - *Workstations*
  - *Upload/Download*



Networks

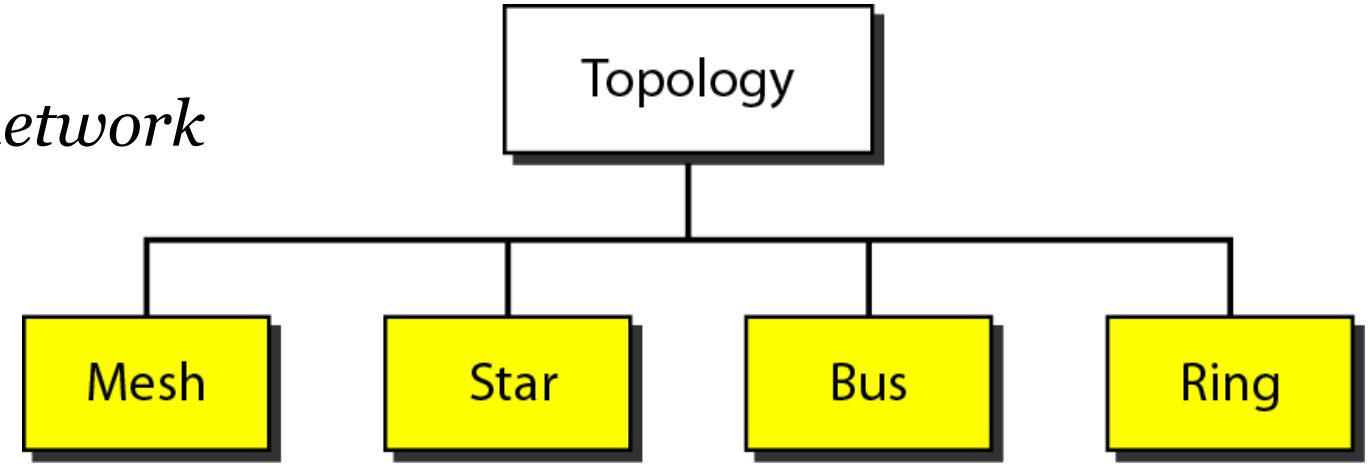
- A *network* is a set of devices (often referred to as *nodes*) connected by communication *links*
- A *node* can be a computer, printer, or any other device
  - It is capable of sending/receiving data generated by other nodes on the network
- A *link* can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.

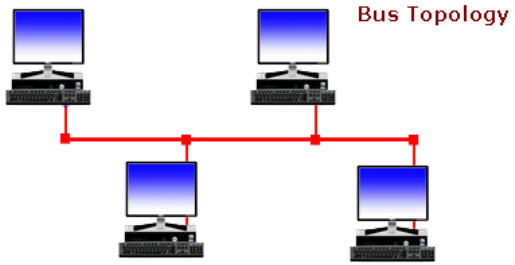


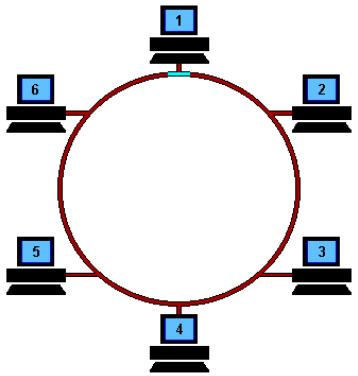


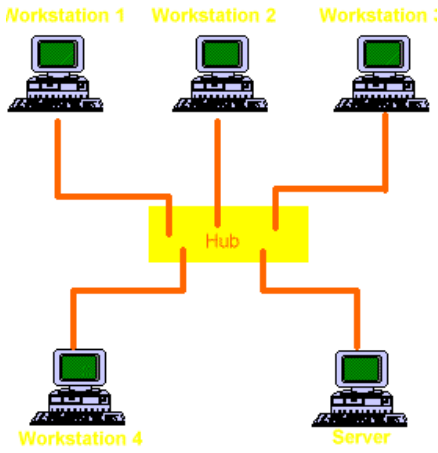
Network Topology

- Topology:
  - *The physical layout of a network*
- *Types*
  - *Bus*
  - *Ring*
  - *Star*
  - *Mesh*
  - *Hybrid etc*





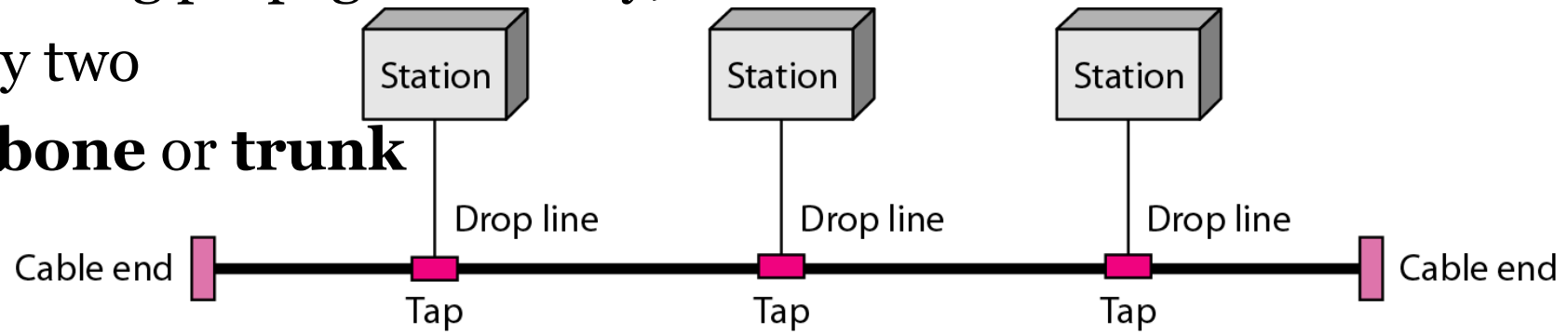




Further details about Network Topologies

Bus Topology

- *Three stations Bus*
- All data are transmitted over the common transmission medium
- All data are able to be received by all nodes in the network virtually simultaneously (disregarding propagation delay)
- The medium has exactly two endpoints called **backbone** or **trunk**



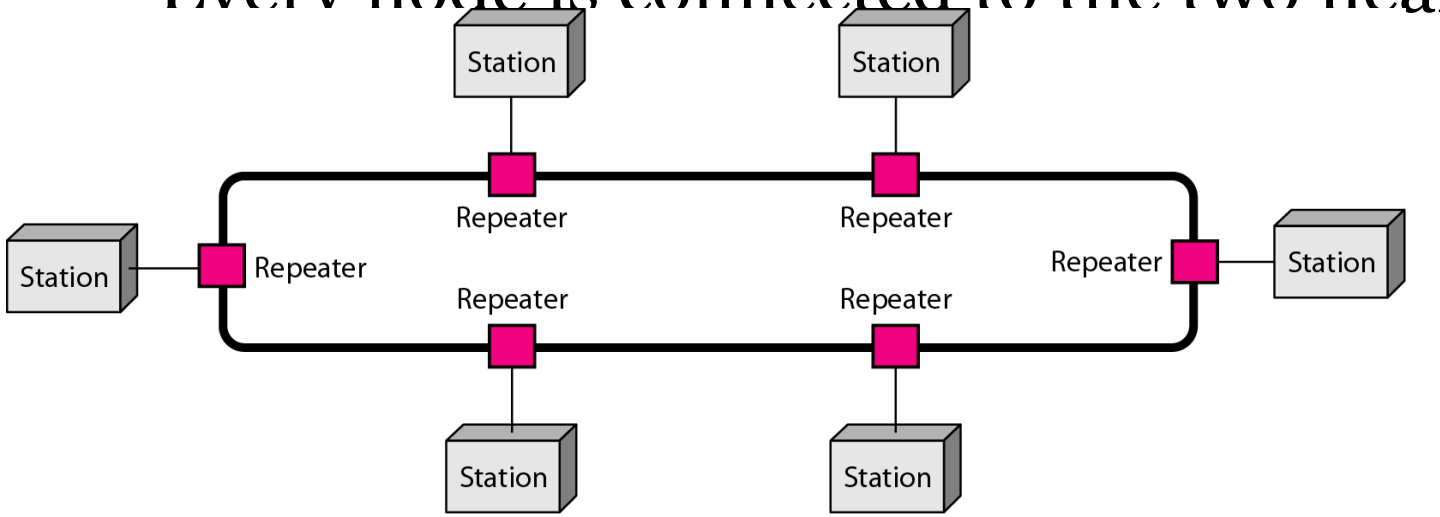
- *Five stations Bus with/without collision*
  - Connected to a single cable

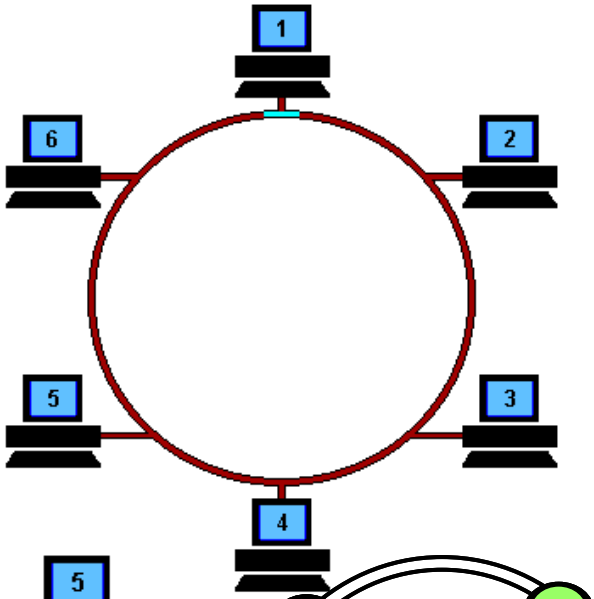
Bus topology

Collision in Bus

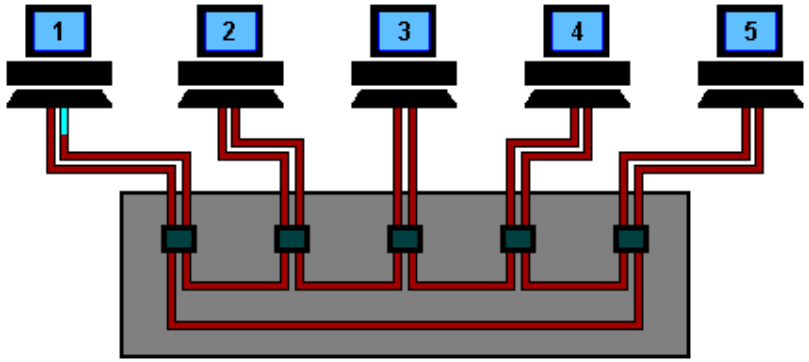
Ring Topology

- *A ring topology connecting six stations*
- Every node is connected to the two nearest nodes so that the

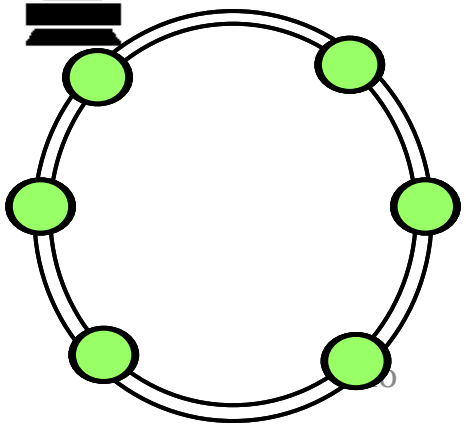




- Simple and Dual Ring
  - The dual ring has twice the capacity as data can travel in both directions simultaneously

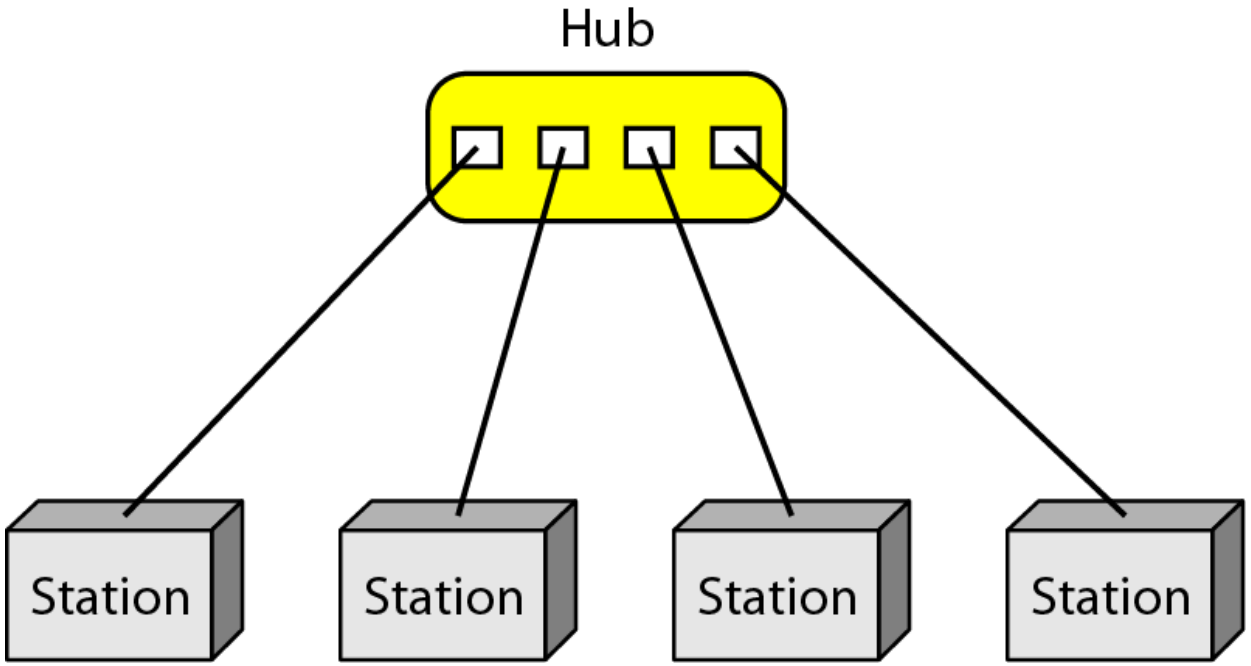


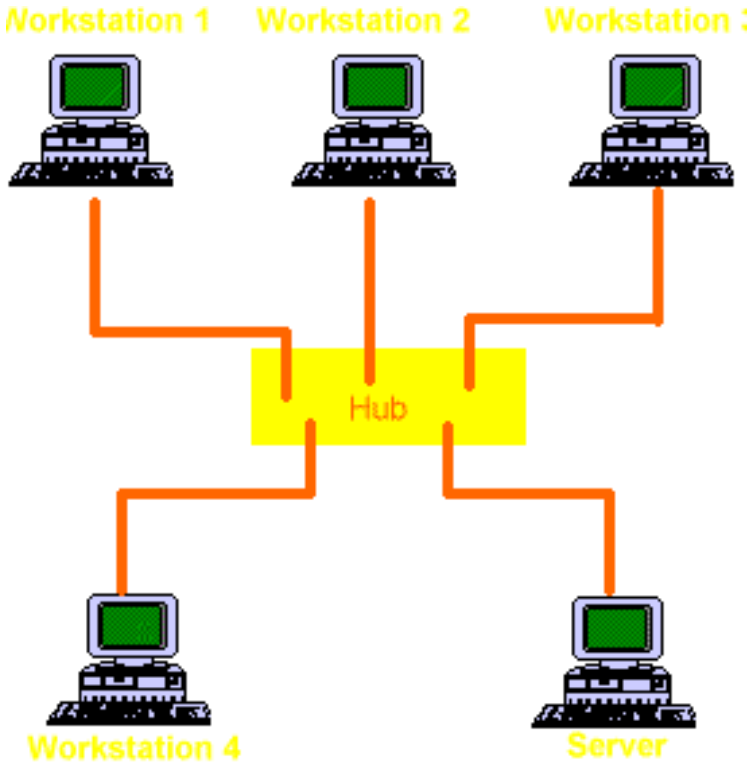
A token in the ring topology



Star Topology

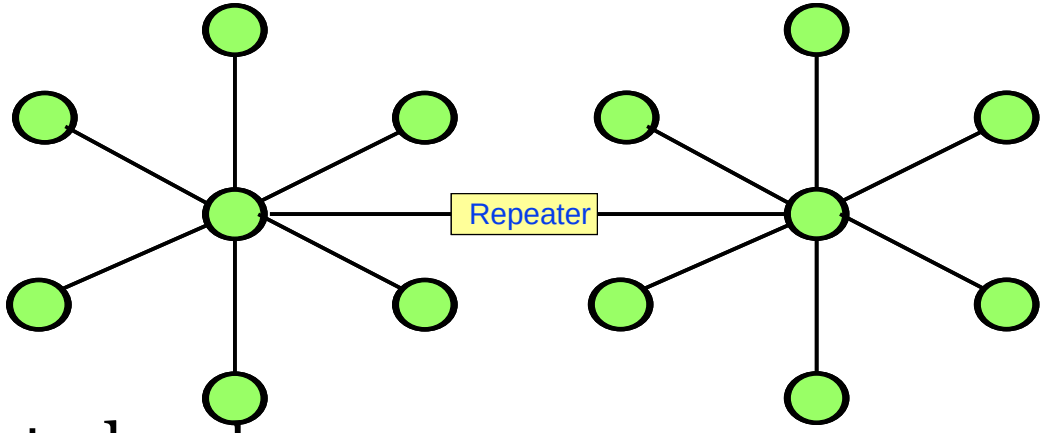
- *Four stations star*
  - connected to a centralized device (*hub/switch/router*)





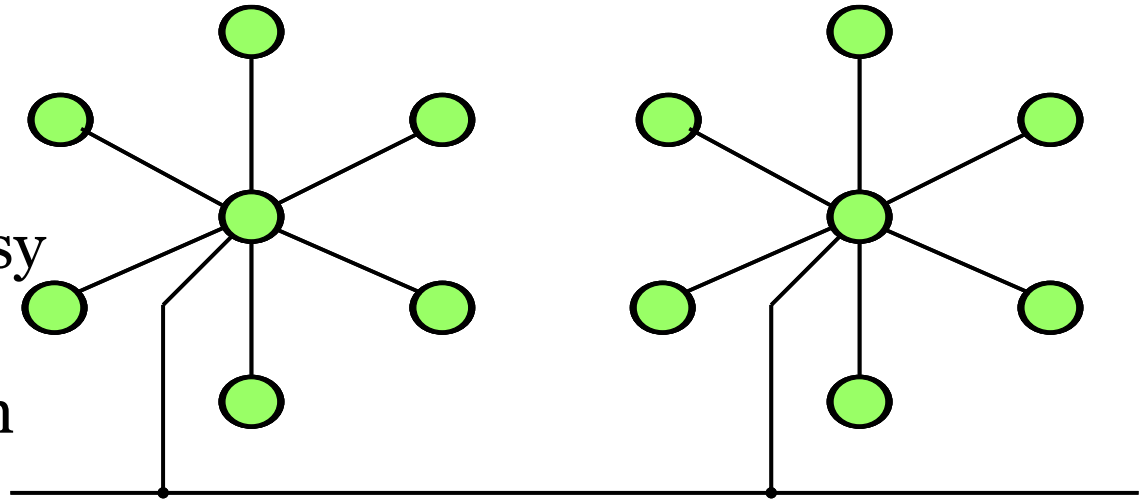
Star Topology-Varients

- *Simple Star*
  - Already discussed



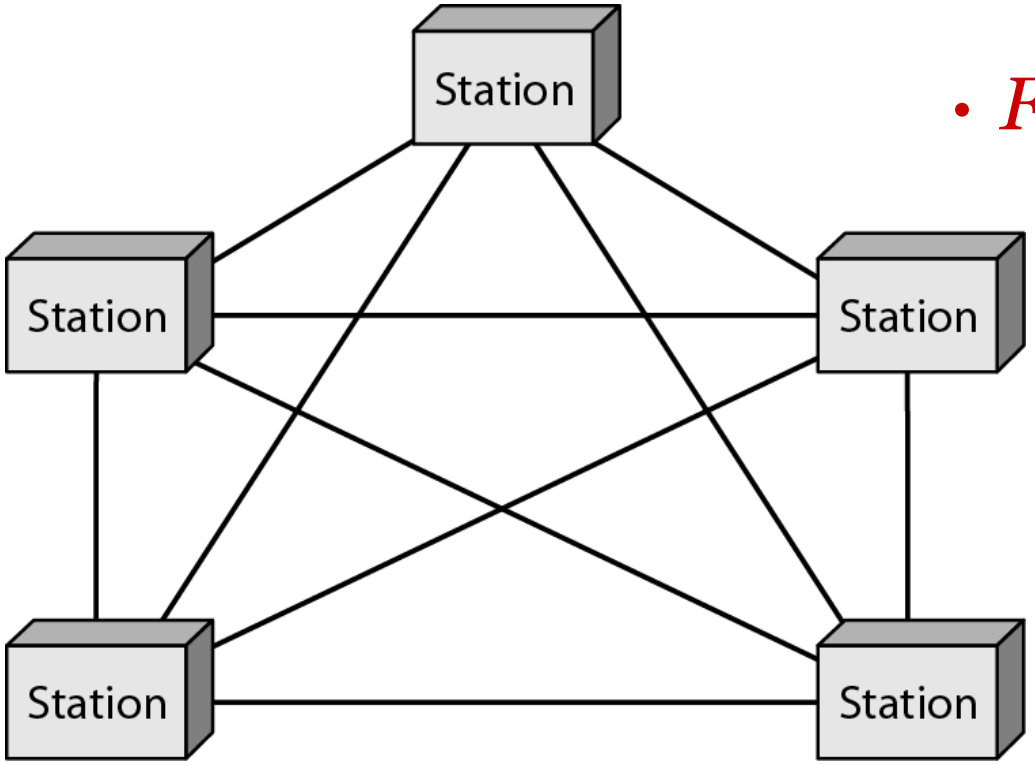
- *Extended Star*
  - Has one or more repeaters between the central node
  - Repeater is used to extend the maximum transmission of the simple star network

- *Distributed Start*
- Connects multiple star networks with a daisy chain in a linear fashion
- Has no hierarchy and no central connection



Mesh Topology

- *Five nodes Mesh:*
  - A fully connected Mesh topology with 5 nodes
- *Number of Connections Required are* ***n(n-1)/2***

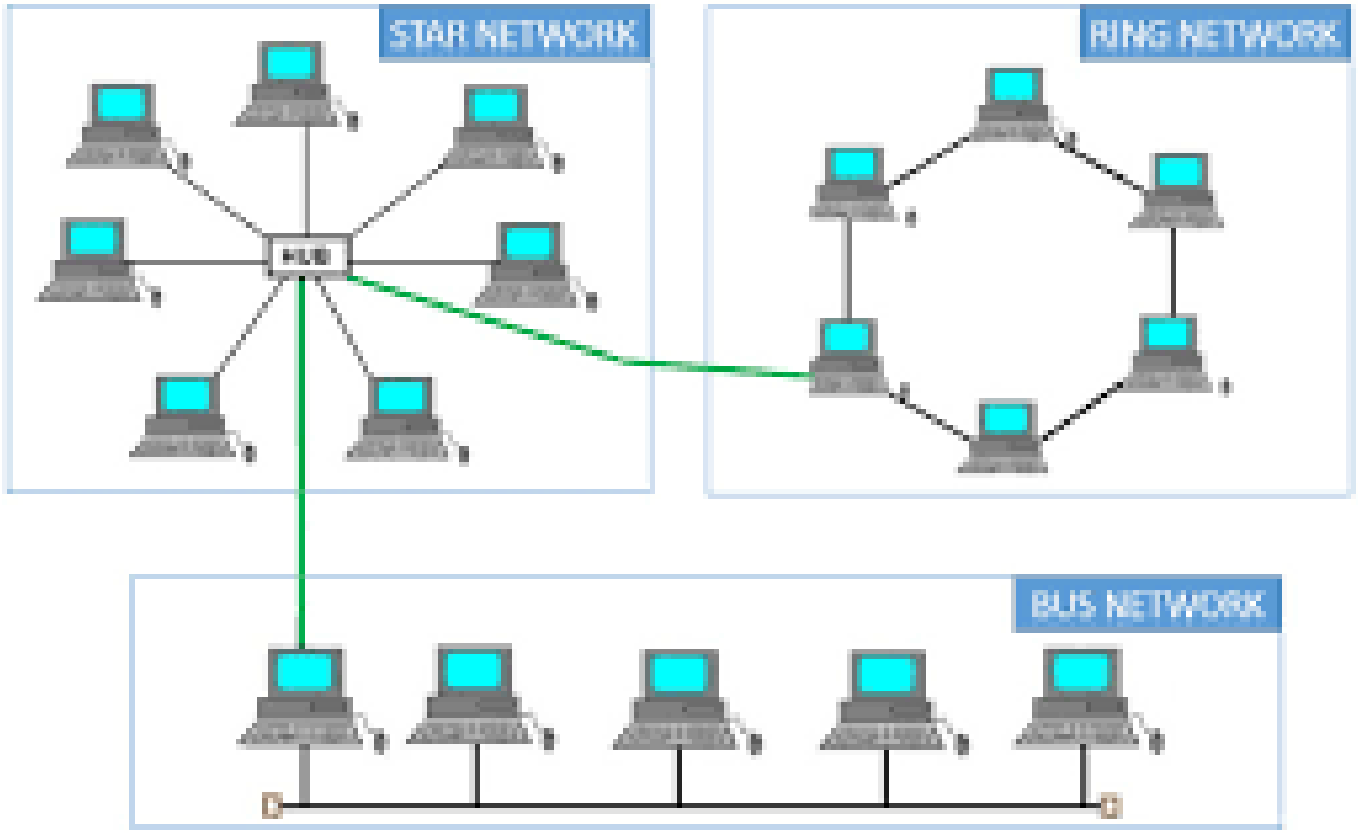


- *Further details*

https://www.geeksforgeeks.org/advantage-and-disadvantage-of-mesh-topology/

Hybrid Topology

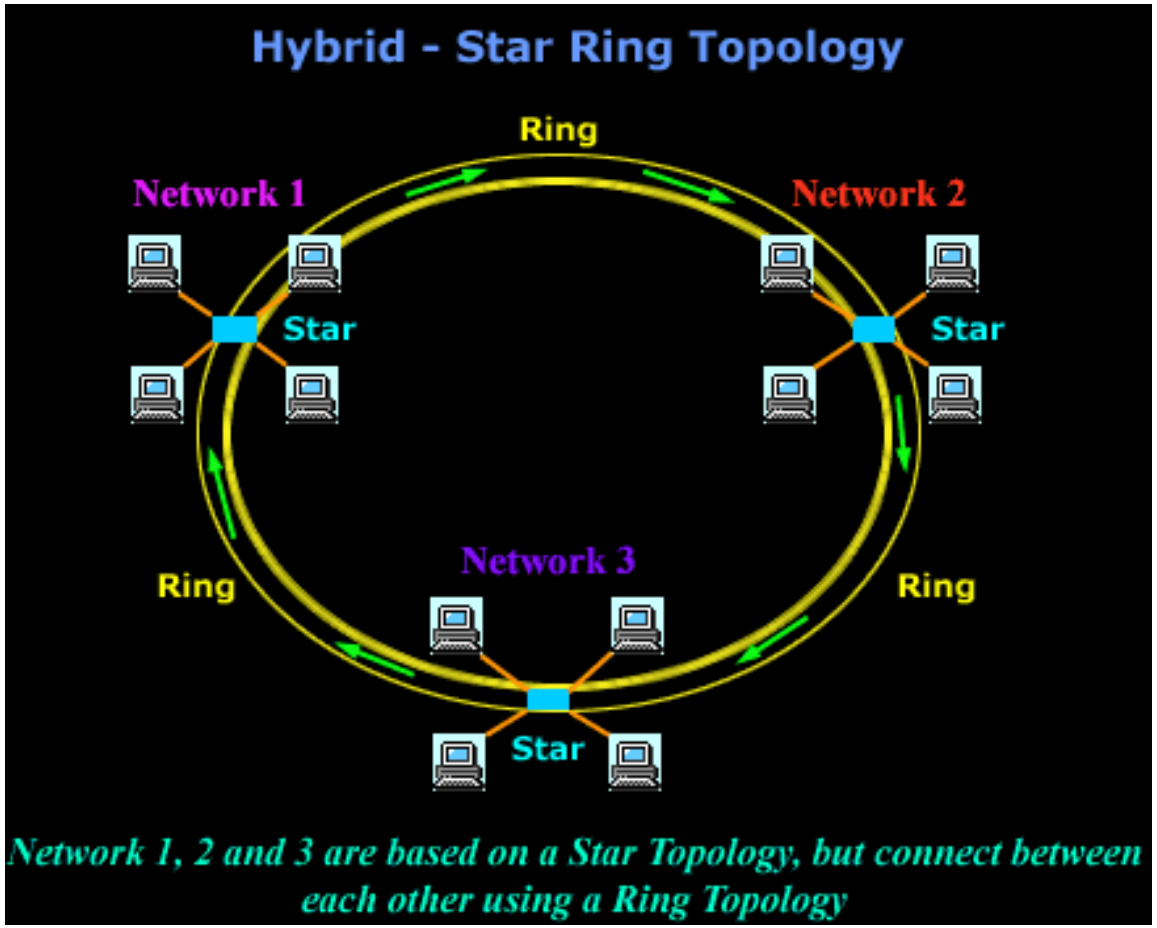
- *Hybrid Topology:*
  - A hybrid topology consists of Star, Ring, and Bus



Start Ring topology

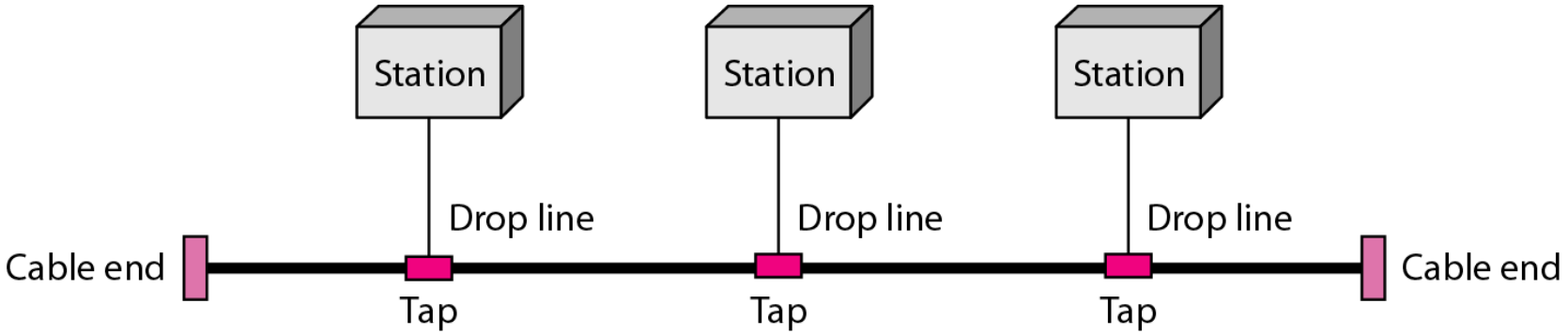
- A star ring network consists of two or more star topologies connected using a multi-station access unit (MU) as a centralized hub

Question: Can you give an example of star ring network topology? [15 seconds time]



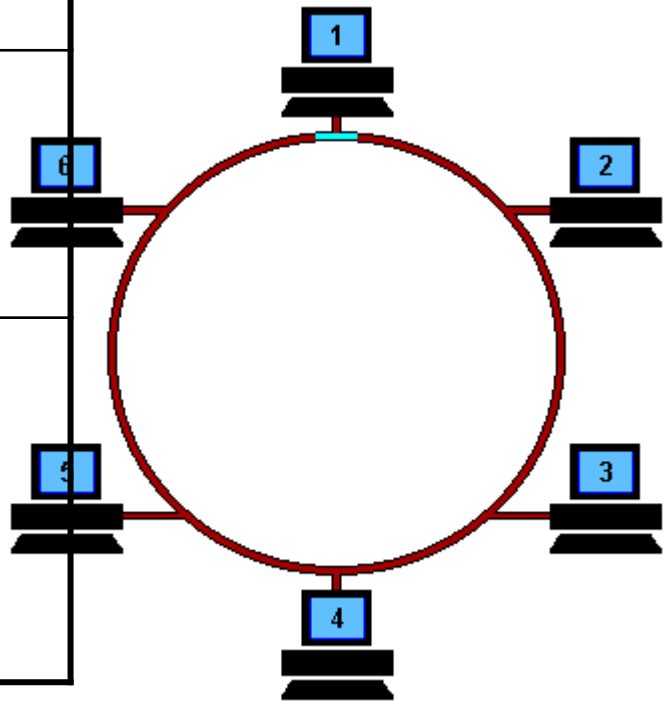
Bus Topology-(Dis)Advantages

Advantages	Disadvantages
Cheap and easy to implement.	Network disruption when computers are added or removed.
Require less cable.	A break in the cable will prevent all systems from accessing the network.
Does not use any specialized network to troubleshoot.	Difficult to troubleshoot.



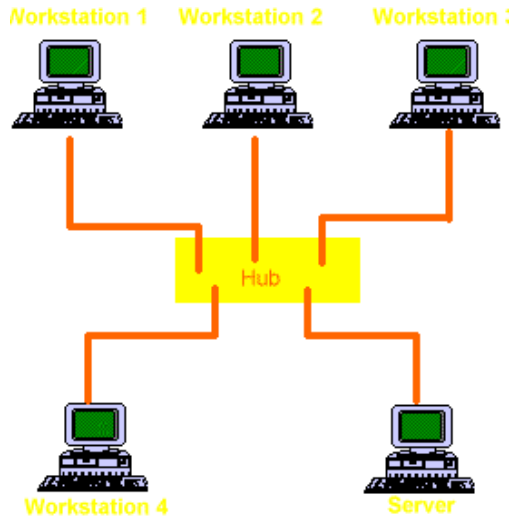
Ring Topology-(Dis)Advantages

Advantages	Disadvantages
Cable faults are easily located, making troubleshooting easier.	Expansion to the network can cause network disruption.
Ring networks are moderately easy to Install.	A single break in the cable can disrupt the entire network.



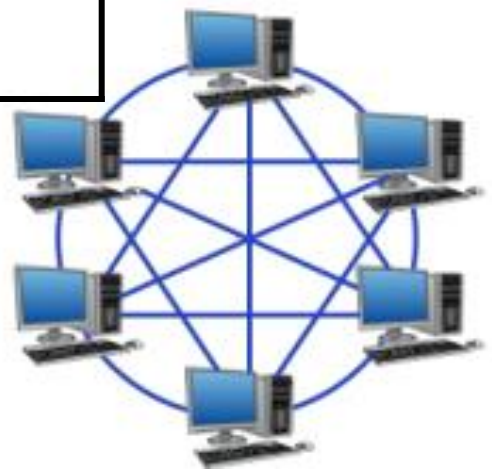
Star Topology-(Dis)Advantages

Advantages	Disadvantages
Easily expanded without disruption.	Requires more cable.
Cable failure affects only a single User.	A break in the cable of central node will prevent all systems from accessing the network.
Easy to troubleshoot and isolate problems.	More difficult to implement.



Mesh Topology-(Dis)Advantages

Advantages	Disadvantages
Provides redundant paths between Devices.	Requires more cable than the other LAN topologies.
The network can be expanded without disruption to current users.	Complicated implementation.



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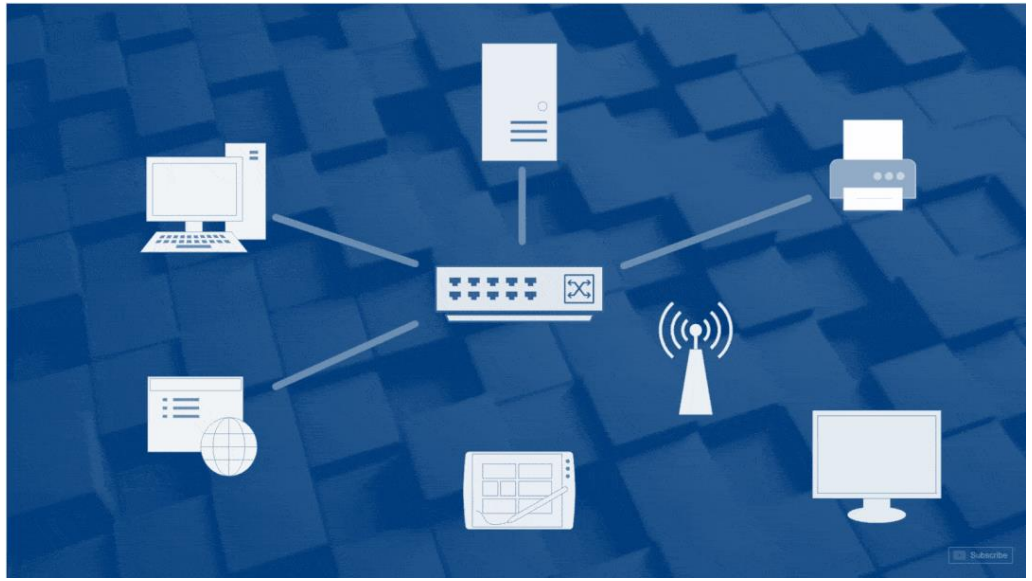
Networks Categories

- Networks are categorized based on different factors,
- *Geographical span:*
  - Local Area Networks (LANs)
  - Metropolitan Area Networks (MANs)
  - Wide Area Networks (WANs)
- *Structure:*
  - Client-server
  - Peer-to-peer
- *Type of connections:*
  - Wired
  - Wireless



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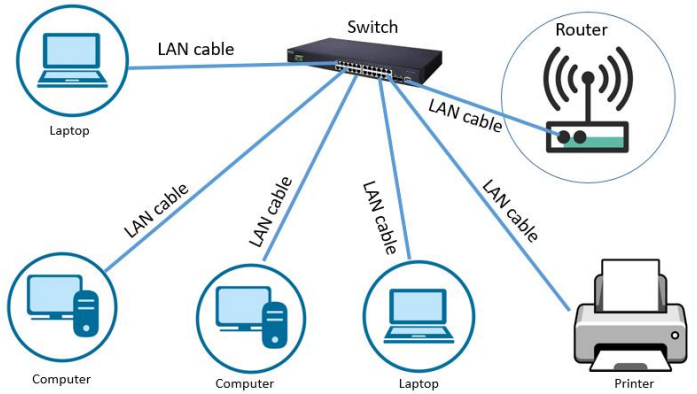
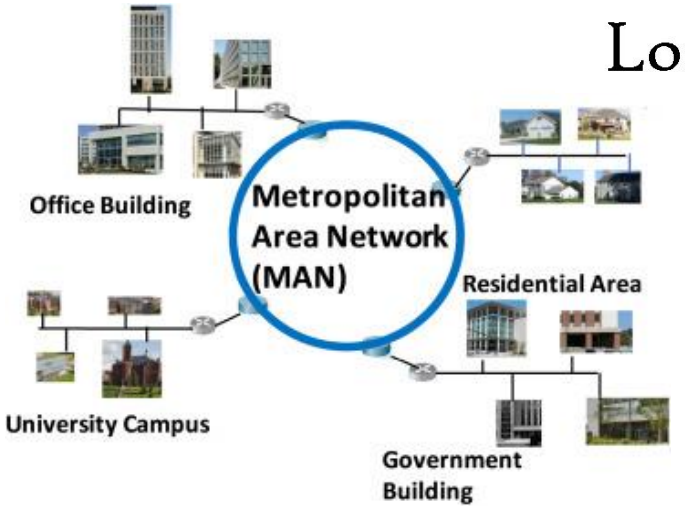
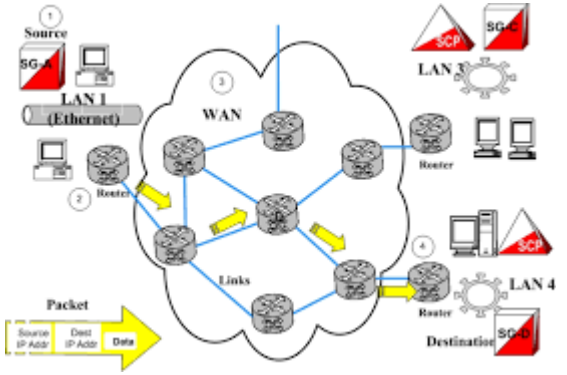
Geographical Networks

- *Local Area Networks (LANs)*
  - Short distances
  - Designed to provide local interconnectivity
- *Metropolitan Area Networks (MANs)*
  - Provide connectivity over multiple buildings
- *Wide Area Networks (WANs)*
  - Long distances
  - Provide connectivity over large area
- *Other Categories*
  - *Personal Area Network (PAN)*
  - *Storage/System Area Networks (SAN)*
  - *Body Area Network (BAN)*
  - *Campus Are Network (CAN), etc.*



Local Area Network





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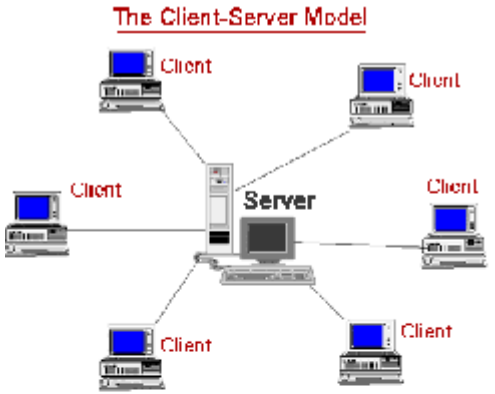
Geographical Networks-Classifications

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

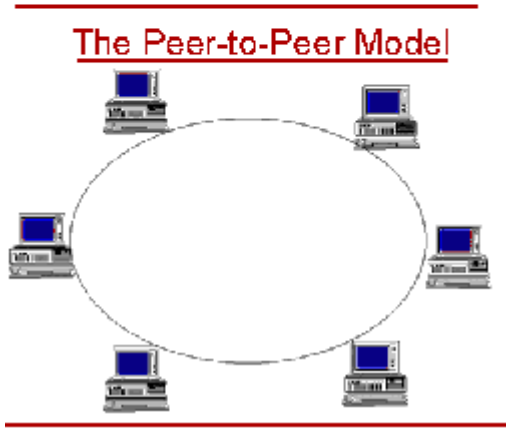
Slides taken from Dr. Ying Weng lecture

Network Structure

- *Client -server:*
  - Acts as a medium to access services and resources from a central computer using a WAN or LAN
  - The Client-server network is mainly used for game hosting, web services, and personal networks



- *Peer-to-peer:*
  - Authorizes to link computers to a single system
  - A distributed application architecture that splits tasks between peers
  - A peer is a node that delivers the exact functionality as another
    - For example, two PCs in a network are peers.



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Network Connections-Wired

- *Ethernet Networks:*
  - The most common type for creating LANs
  - They employ Ethernet cables, which are usually made up of copper, to connect devices like computers, routers, and switches.
- *Fiber Optic Networks:*
  - They use light signals to transmit data over thin strands of glass or plastic known as fiber optic cables
  - They are known for their high-speed data transfer capability
- *Coaxial Cable Networks:*
  - These were used in cable television and early computer networks

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Network Connections-Wireless

- *Wi-Fi Networks:*
  - The most well-known type of wireless networks
  - It uses radio waves to connect devices to the internet or each other
- *Bluetooth Networks:*
  - They enable communication between devices over short distances
  - They're typically used for connecting peripherals like wireless mice, keyboards, or headphones to a computer or smartphone.
- *Cellular Networks:*
  - These are used by mobile phones and some IoT devices
  - They have a large network of fixed-location cell towers
  - These networks support voice calls, SMS, and data services, such as 4G and 5G internet access.

Overview

Learning Outcomes:

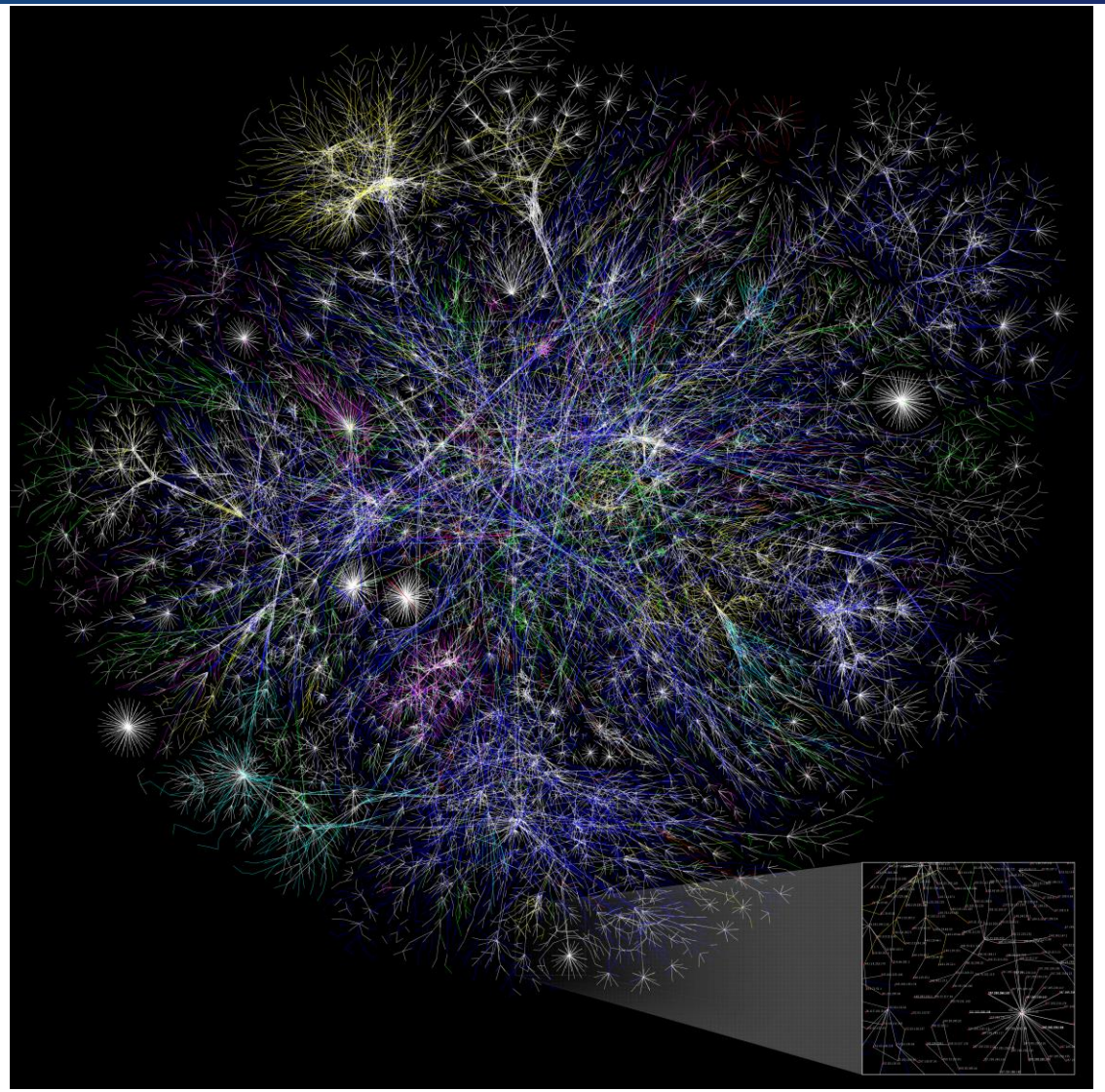
- Learn the basic of networks and networking terminologies
- the types of networks and how they are designed
- the basics of Internet

Overview/roadmap:

- We talked about
  - Data and Communication
  - Network and its types
  - Topologies
- Next we discuss
  - the Internet
  - Protocol
  - End Systems
  - Access Networks and Physical Media
  - Network Functions

The Internet

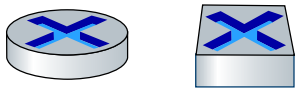
- The network of networks is called the *Internet*
- It has revolutionized many aspects of our daily lives
- The Internet is a communication system
  - that has brought a wealth of information to our fingertips
  - and organized it for our use.



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)

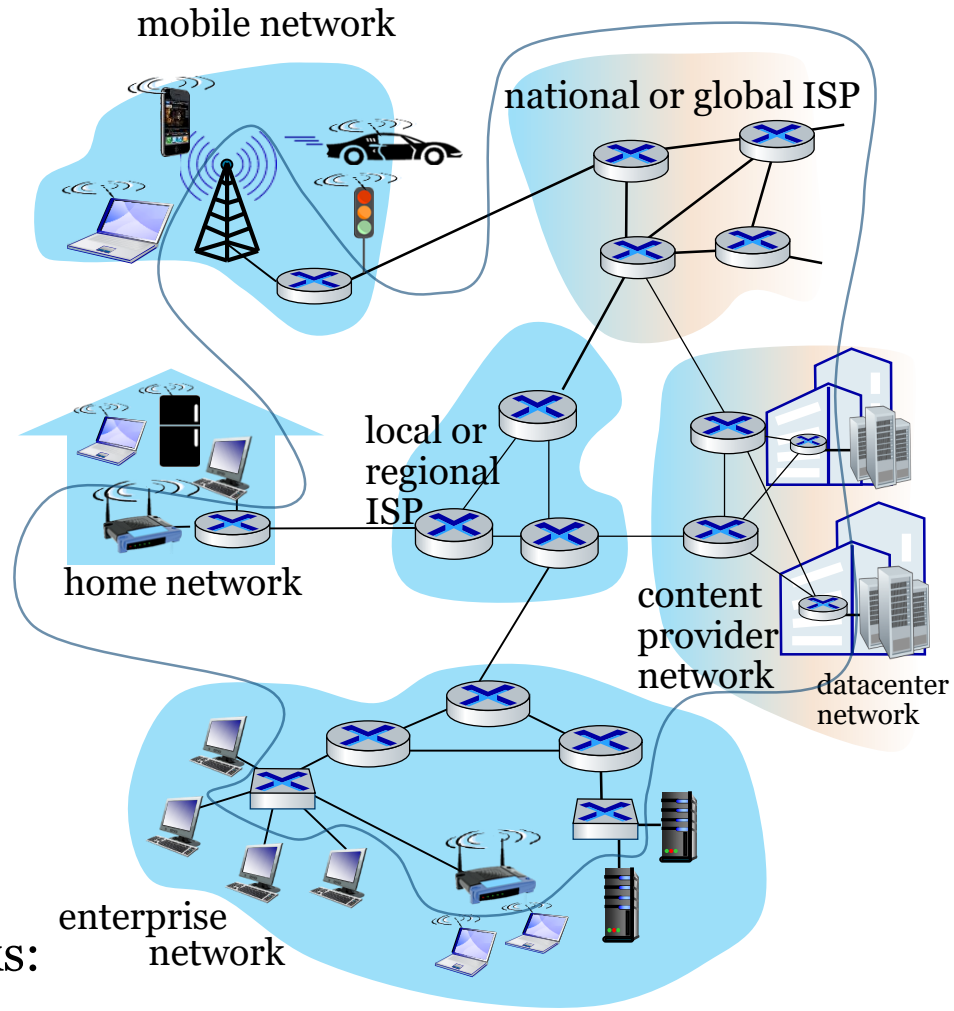
- *routers, switches*

Communication links

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

Networks

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



“Fun” 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

Fitbit

scooters

Internet phones

Gaming devices

sensorized bed mattress

diapers

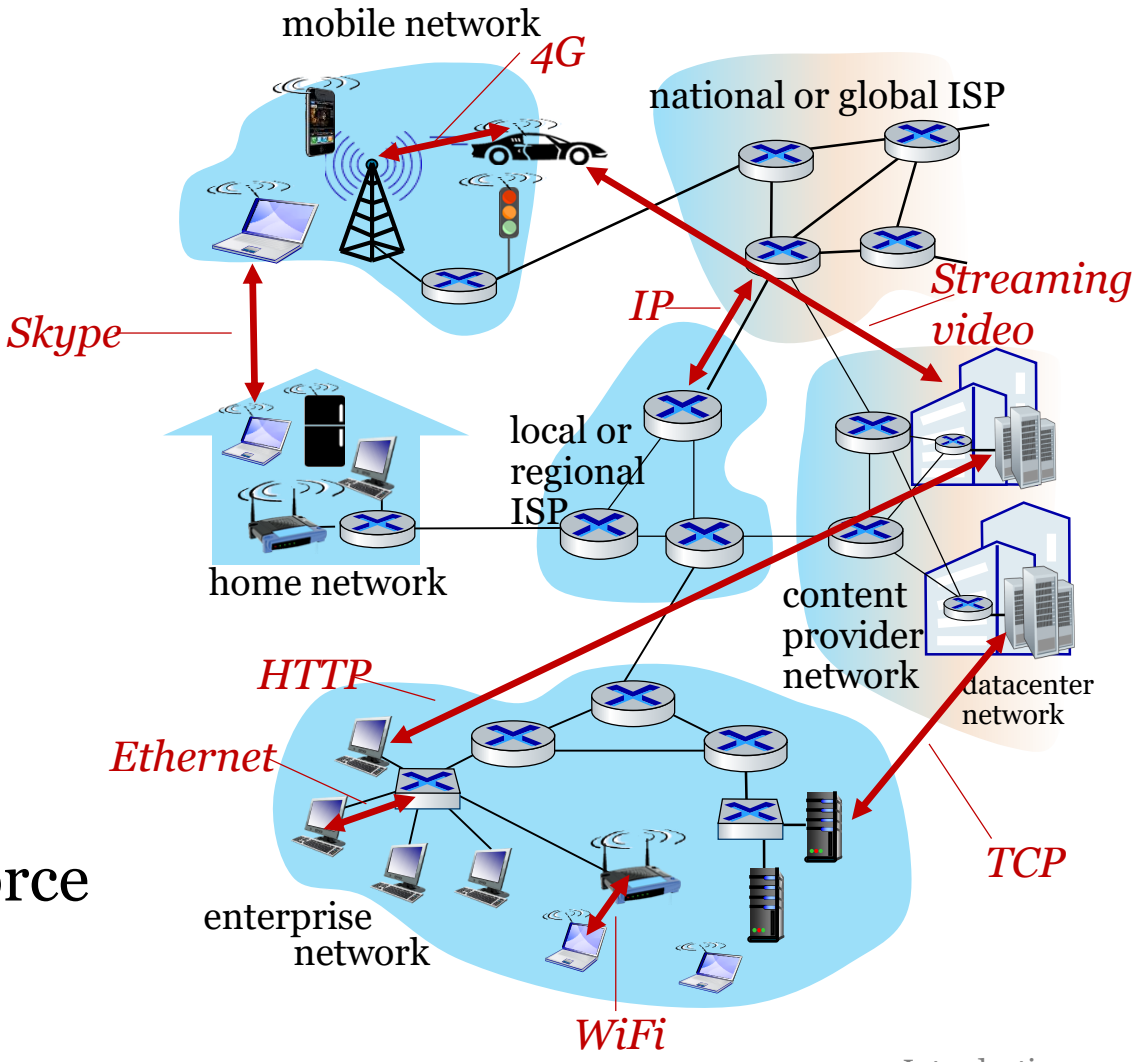
Others?

The Internet: a "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
    - Internet Service Providers

- *Protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet

- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



What's a protocol?

Human protocols:

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

Rules for:

… specific messages sent

… specific actions taken when message received, or other events

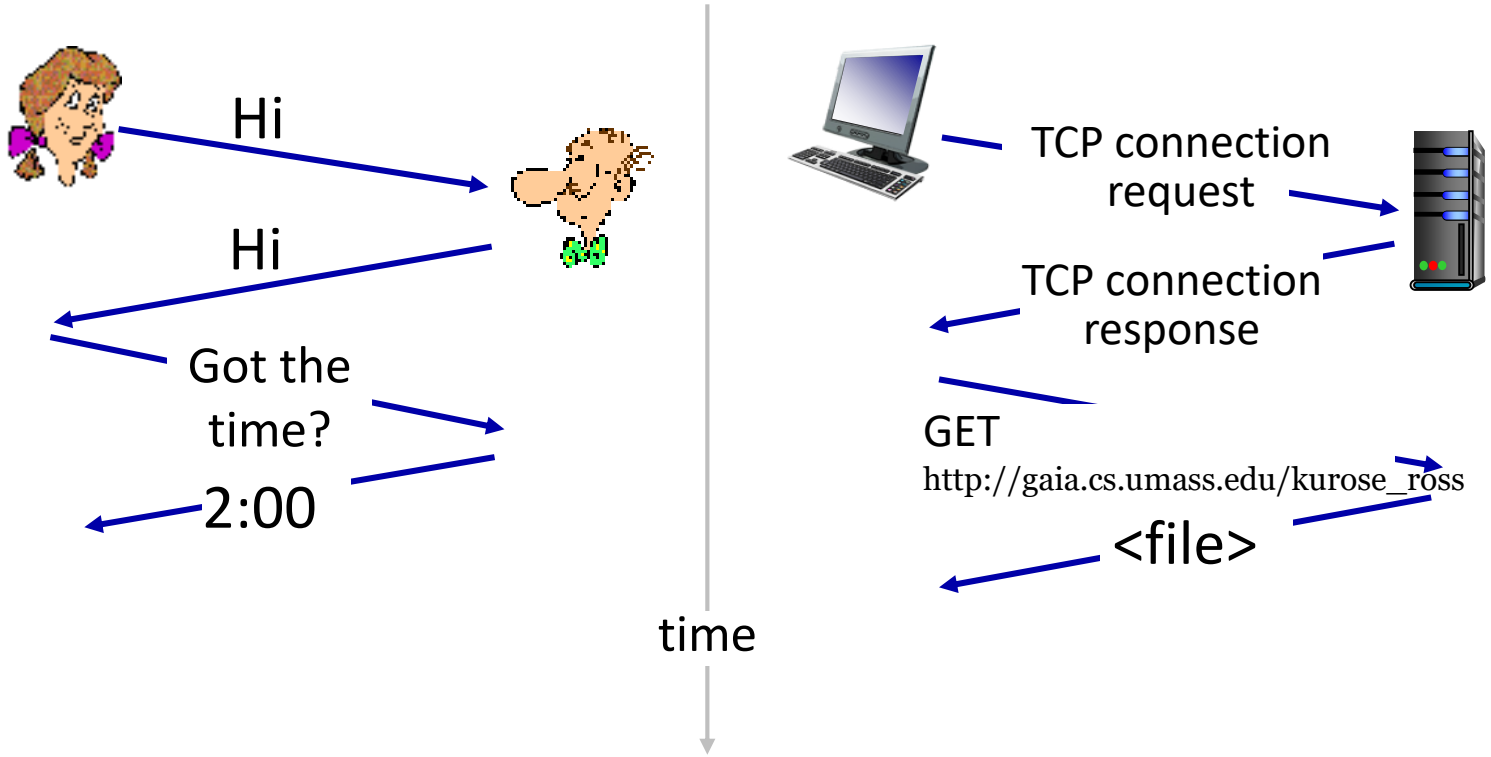
Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the 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:

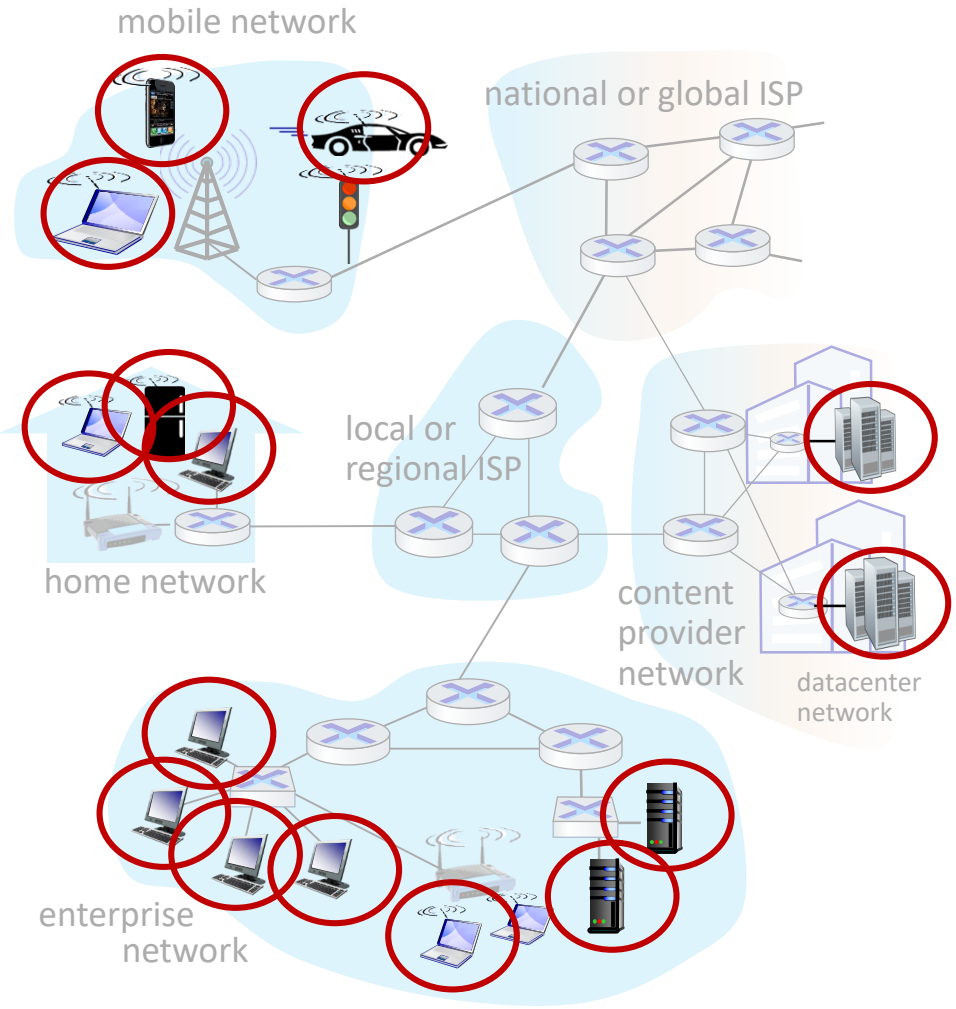


Q: other human protocols?

A closer look at Internet structure

Network edge:

- hosts: clients and servers
- servers often in data centers



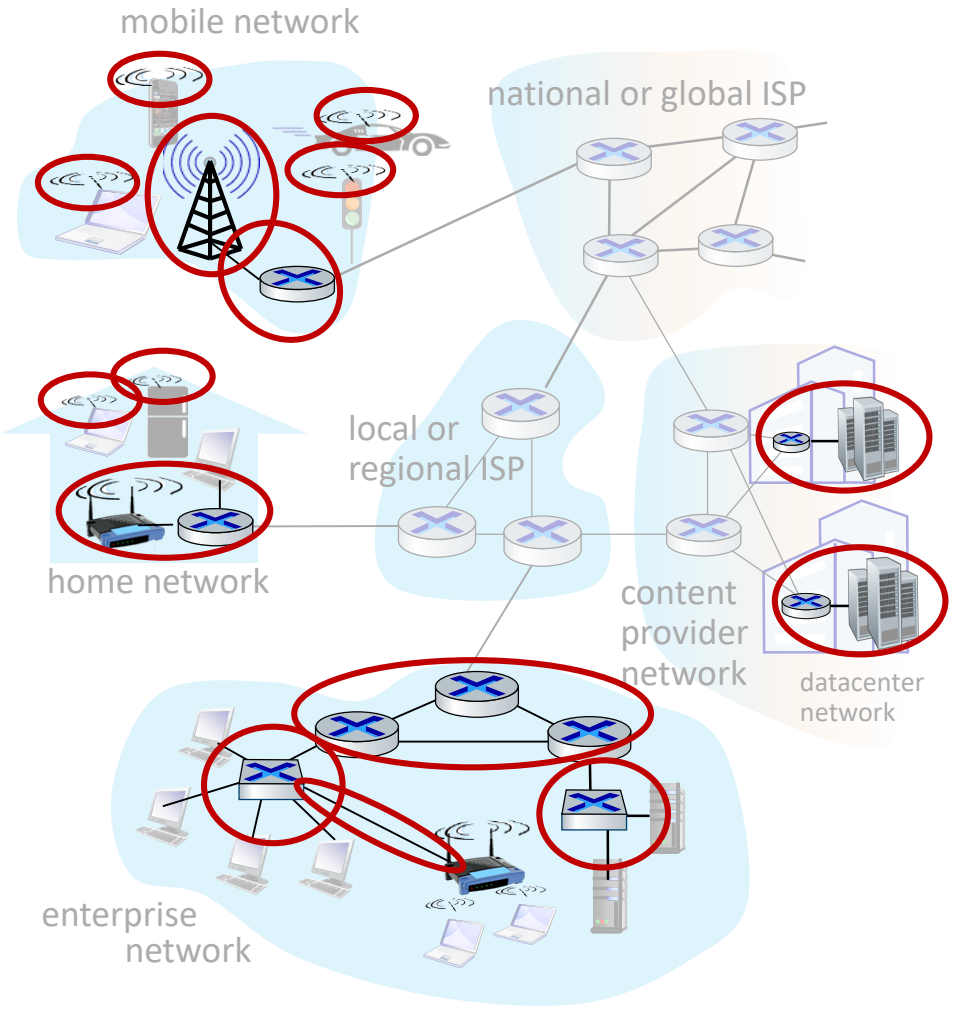
A closer look at Internet structure

Network edge:

- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

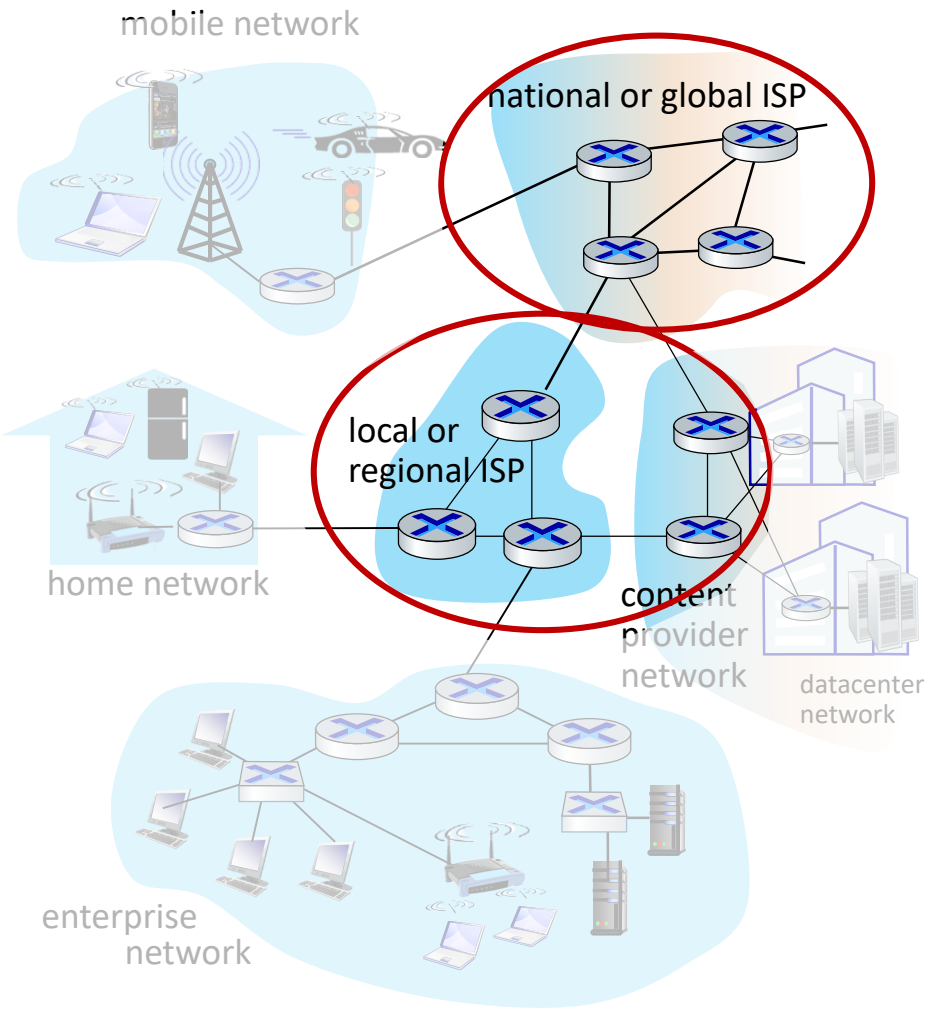
- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

Network core:

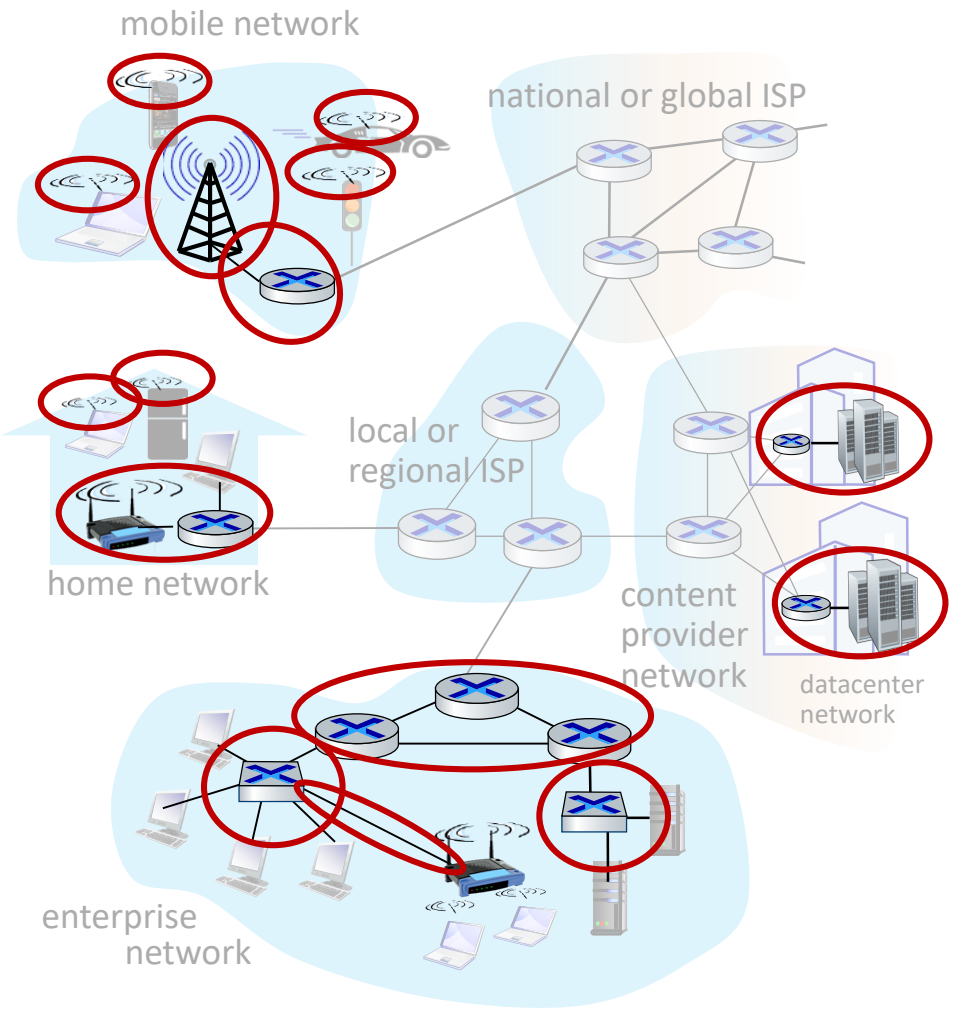
- interconnected routers
- network of networks



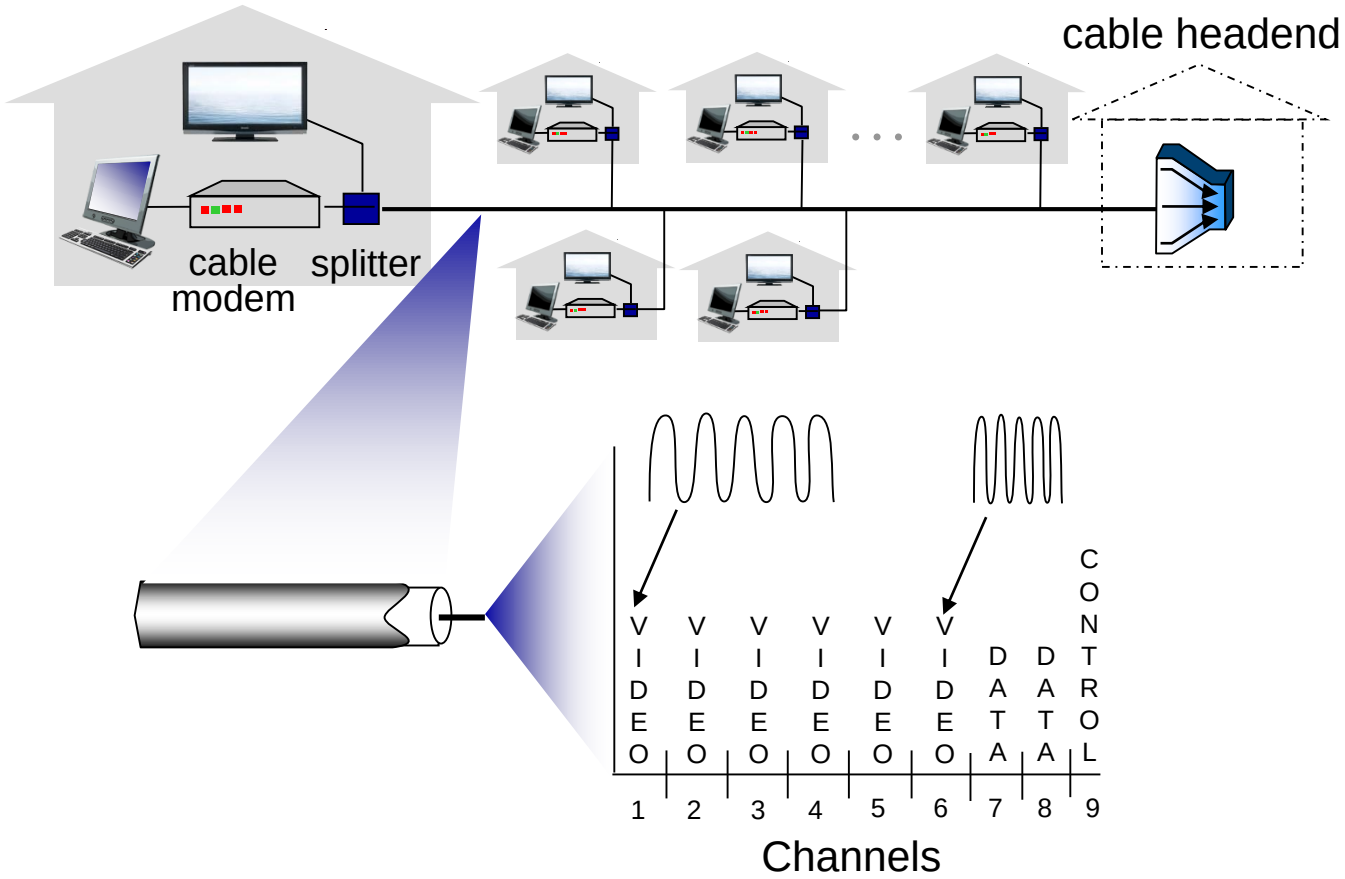
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)

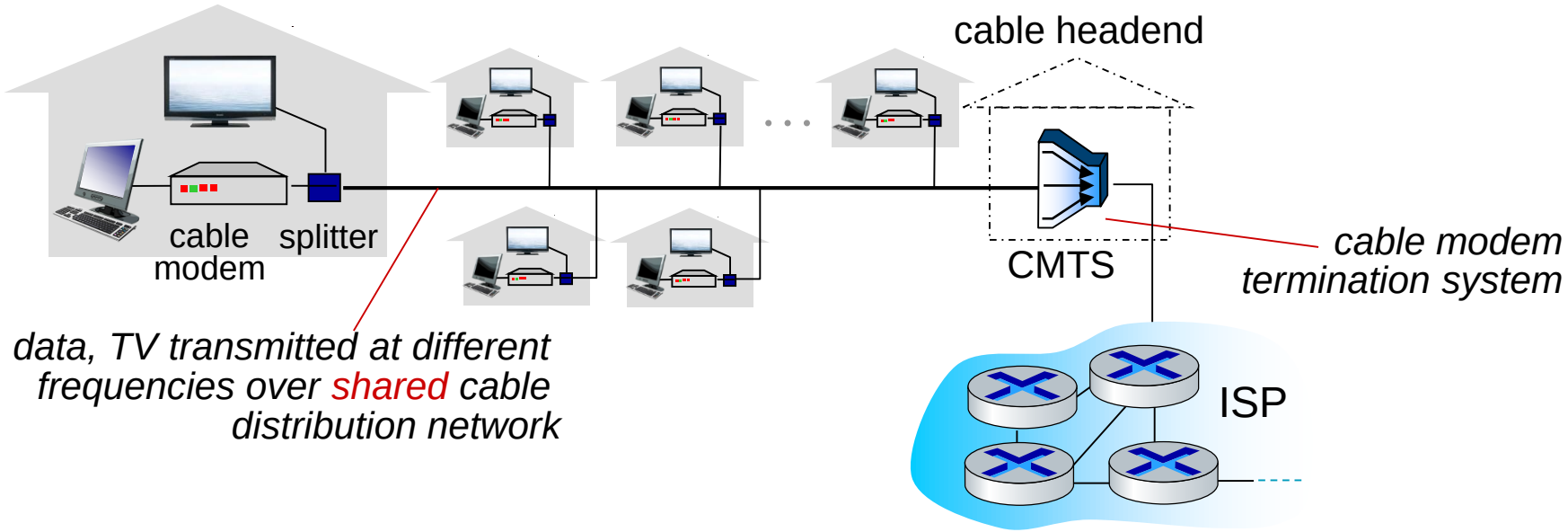


Access networks: cable-based access



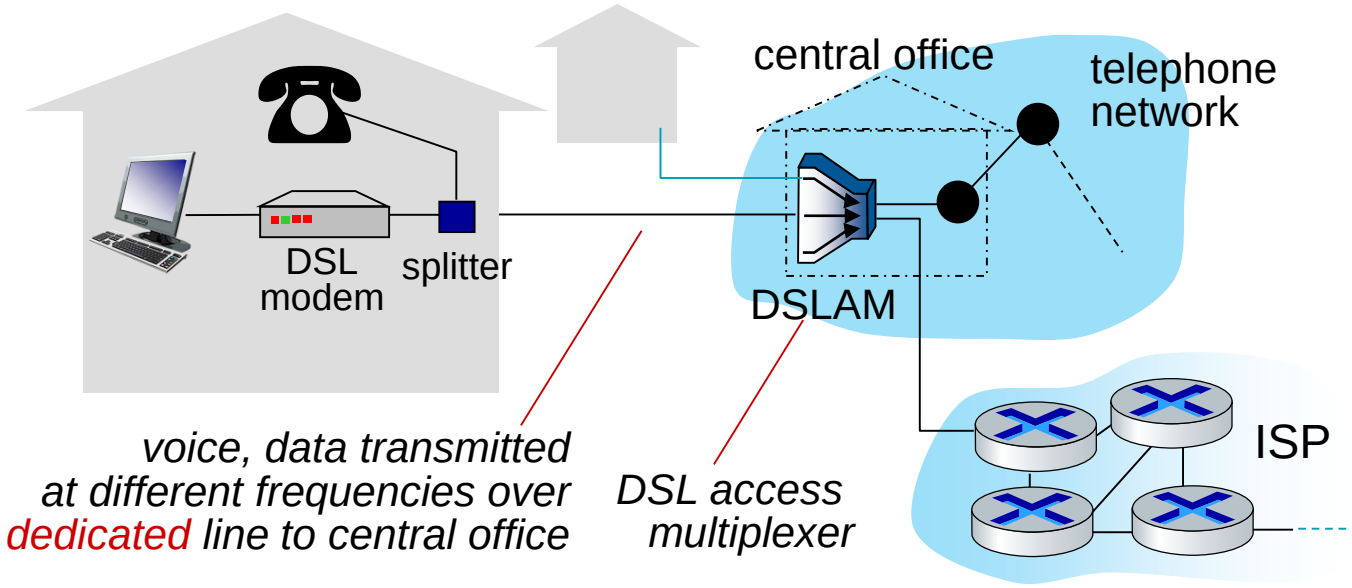
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

Access networks: cable-based access



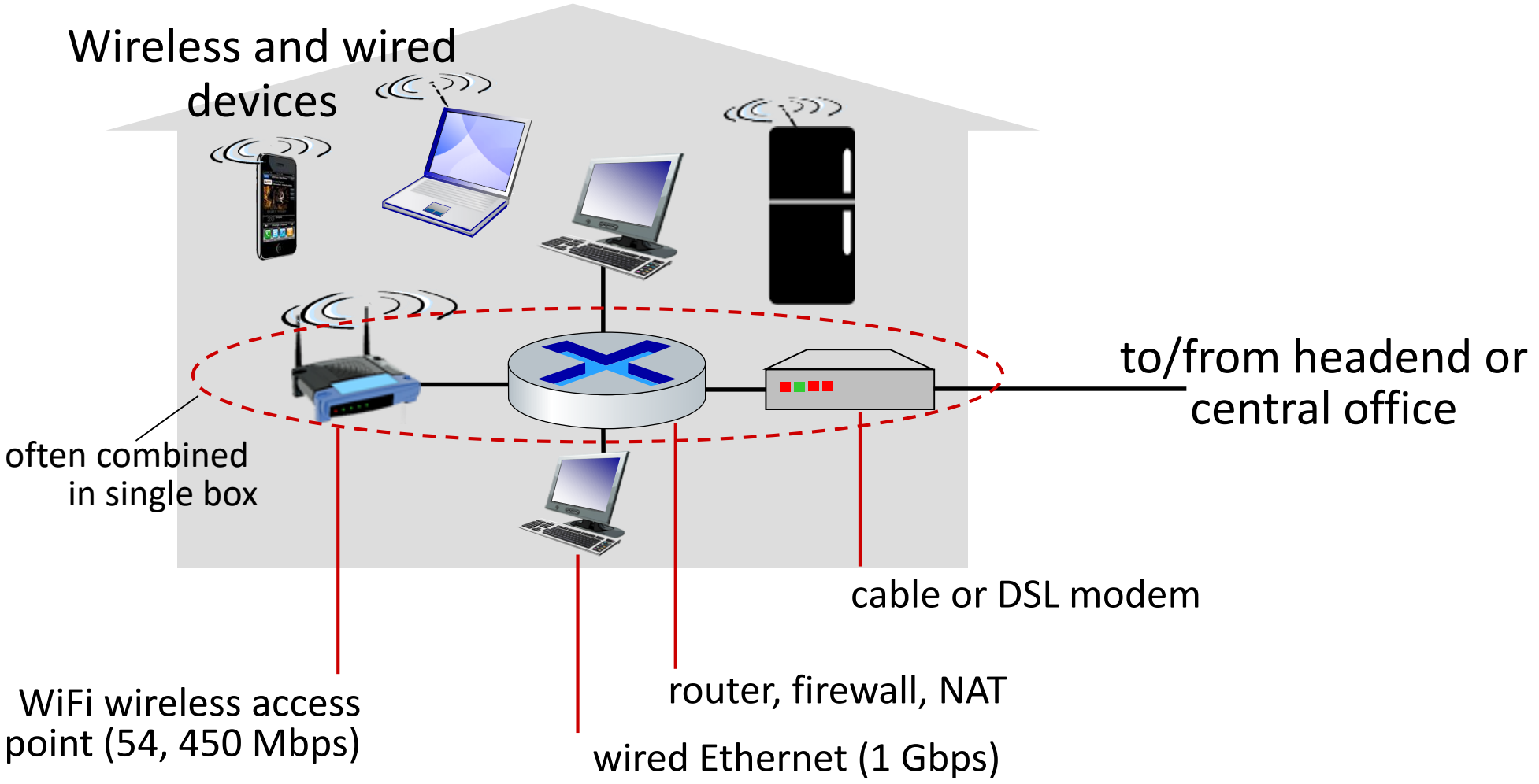
- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks: 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
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Access networks: home networks

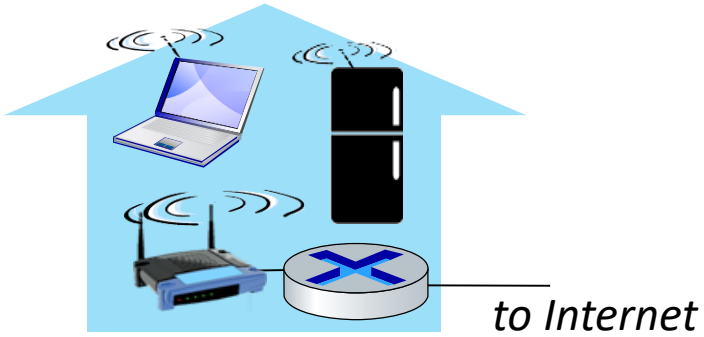


Wireless access networks

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

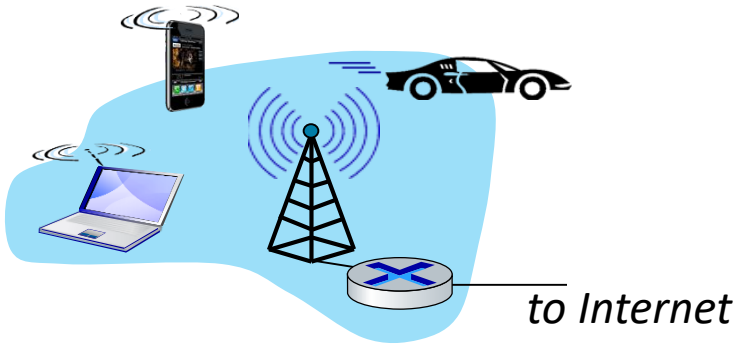
Wireless local area networks (WLANs)

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

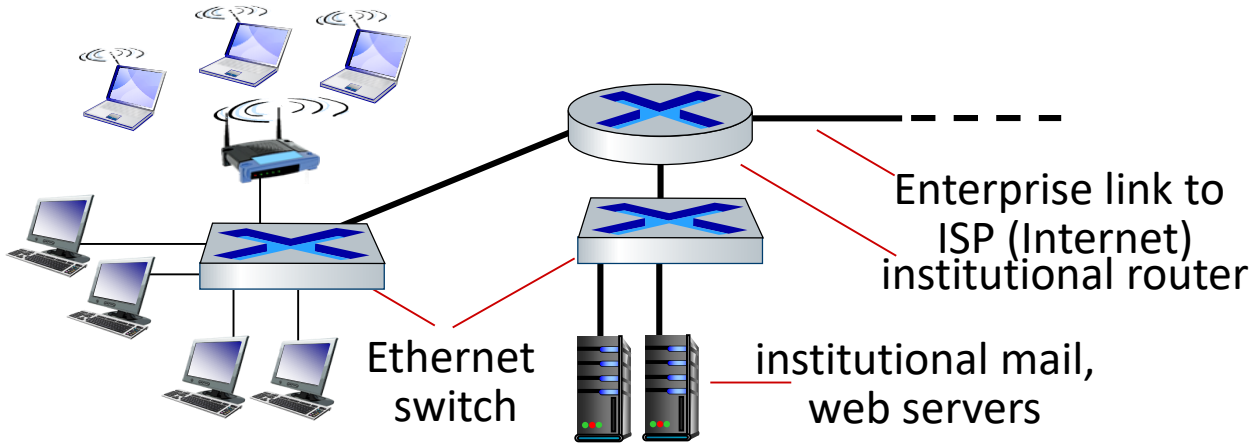


Wide-area cellular access networks

- provided by mobile, cellular network operator (10’s km)
- 10’s Mbps
- 4G/5G cellular networks



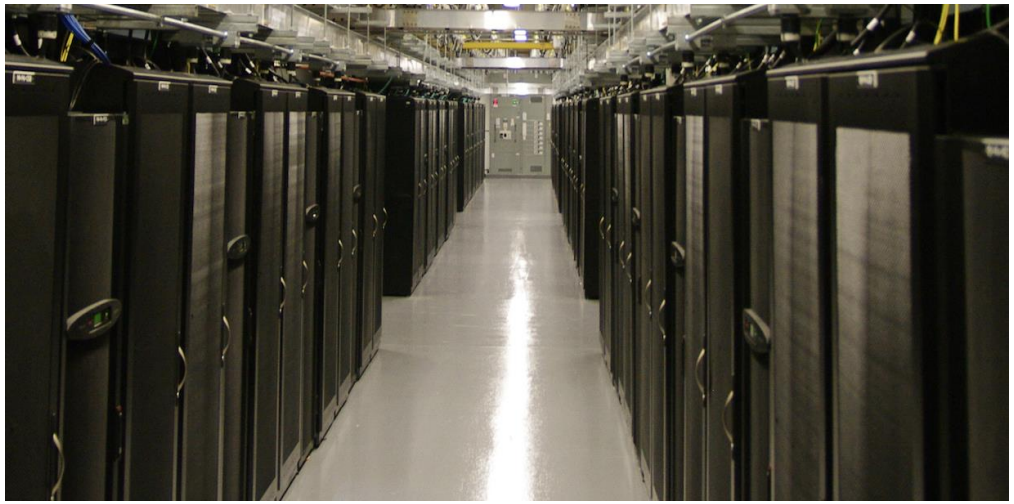
Access networks: enterprise networks



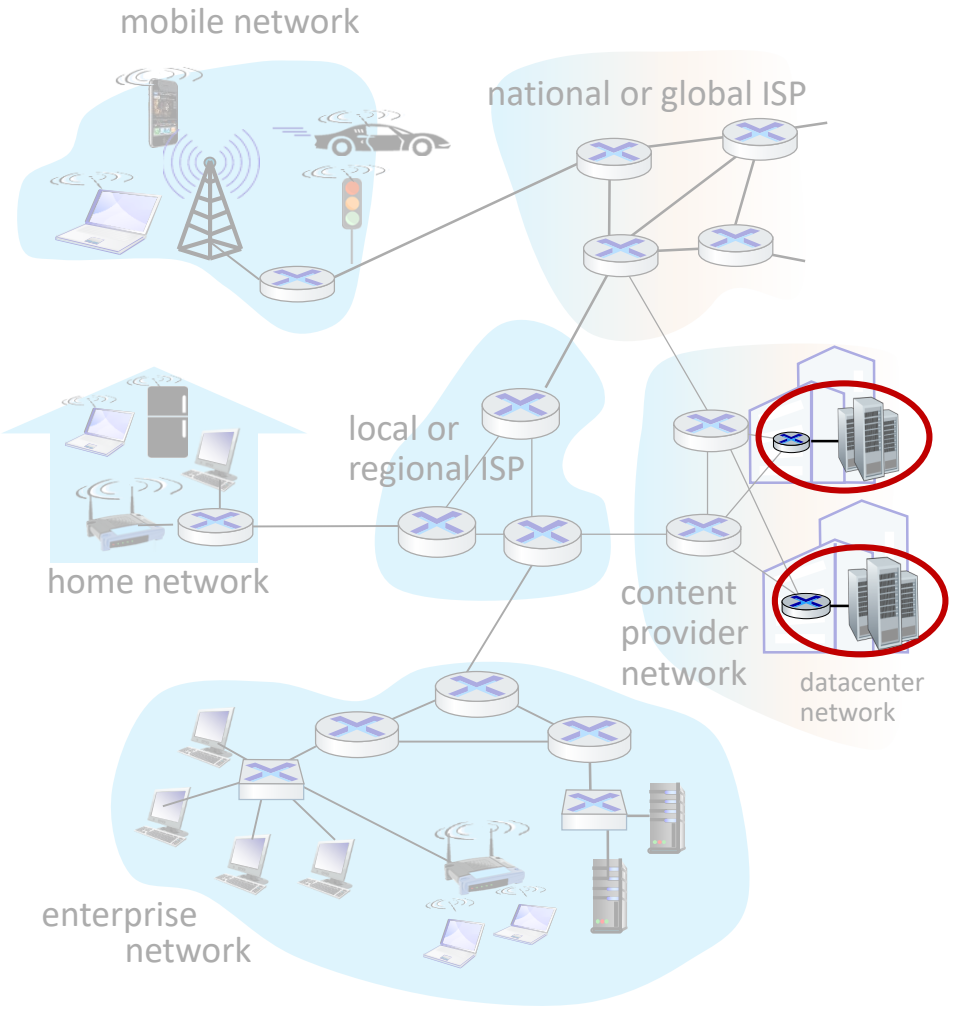
- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers
- Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
- WiFi: wireless access points at 11, 54, 450 Mbps

Access networks: data center networks

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



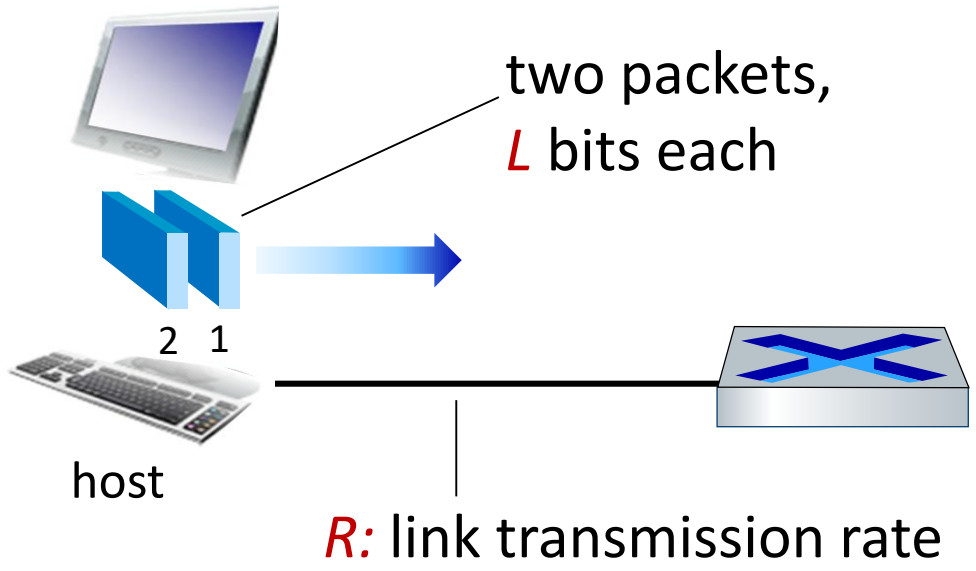
Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



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*



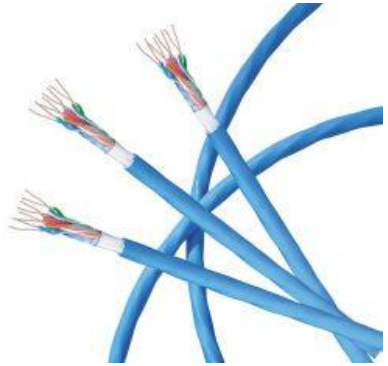
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Links: 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: 10Gbps Ethernet



Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (10's-100's Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

Links: physical media

Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- Wide-area (e.g., 4G/5G cellular)
  - 10's Mbps (4G) over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- Terrestrial microwave
  - point-to-point; 45 Mbps channels
- Satellite
  - up to < 100 Mbps (Starlink) downlink
  - 270 msec end-end delay (geostationary)

Overview

Learning Outcomes:

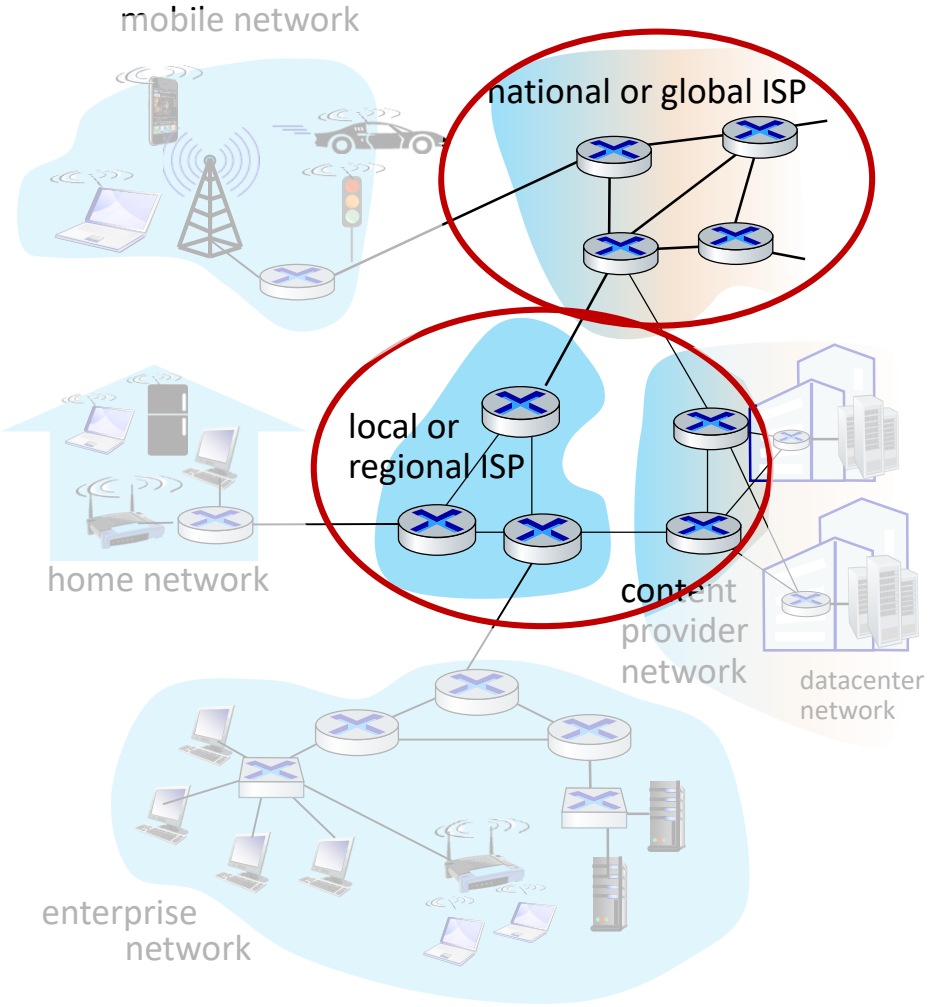
- Learn the basic of networks and networking terminologies
- the types of networks and how they are designed
- the basics of Internet

Overview/roadmap:

- We talked about
  - Data and Communication
  - Network and its types
  - Topologies
  - the Internet
  - Protocol
  - End Systems
  - Access Networks and Physical Media
- Next we discuss
  - Network Functions

The network core

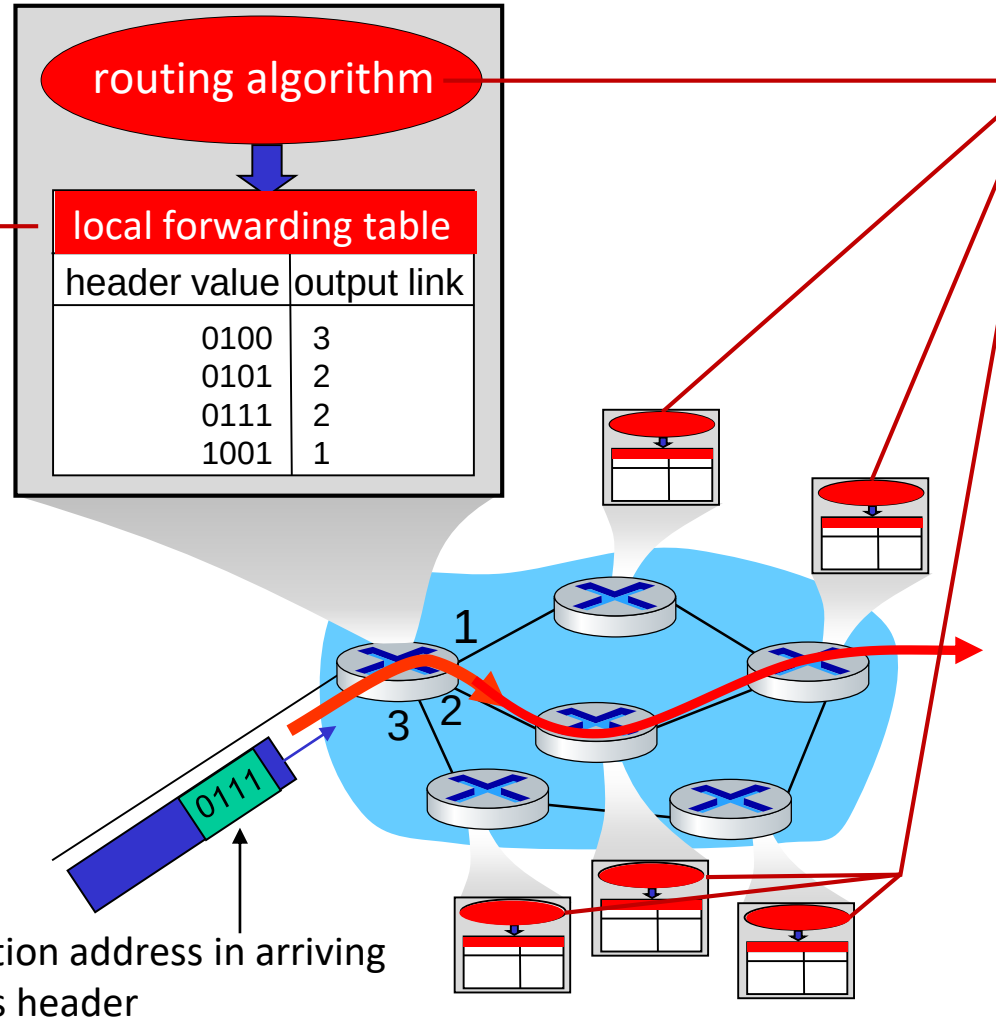
- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - network forwards packets from one router to the next, across links on path from source to destination



Two key network-core functions

Forwarding:

- aka "switching"
- *local* action: move arriving packets from router's input link to appropriate router output link

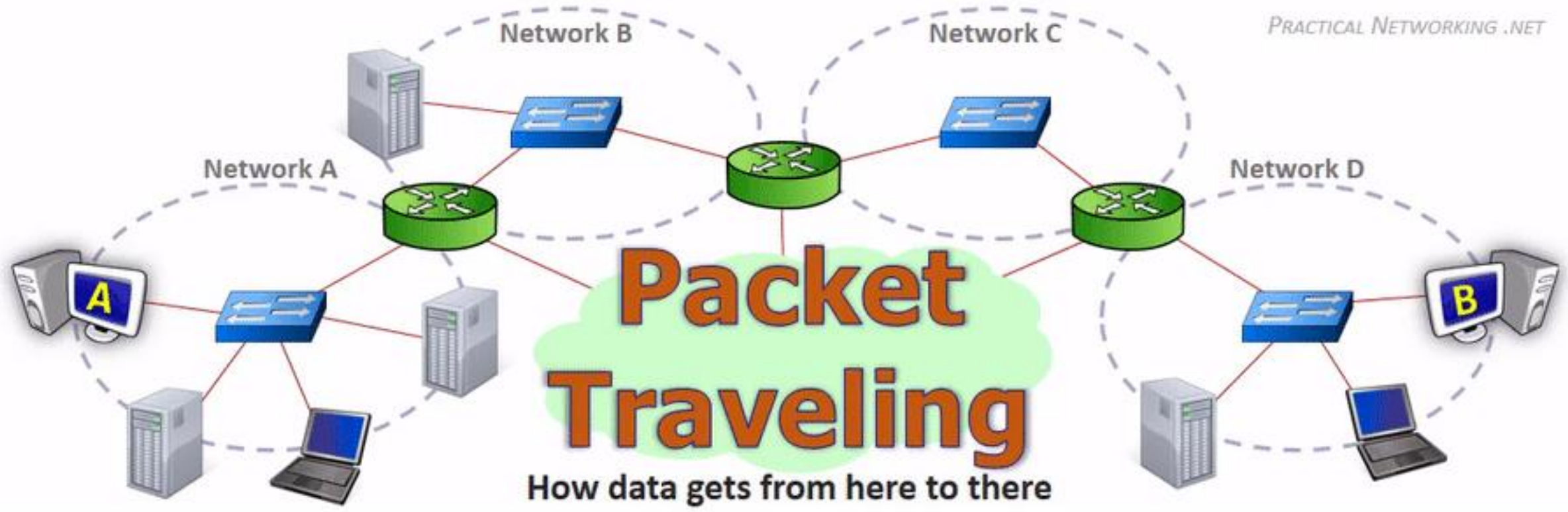


Routing:

- *global* action: determine source-destination paths taken by packets
- routing algorithms

Packet Traveling

Tracert/Traceroute Format
Hop RTT1 RTT2 RTT3 Domain Name [IP Address]



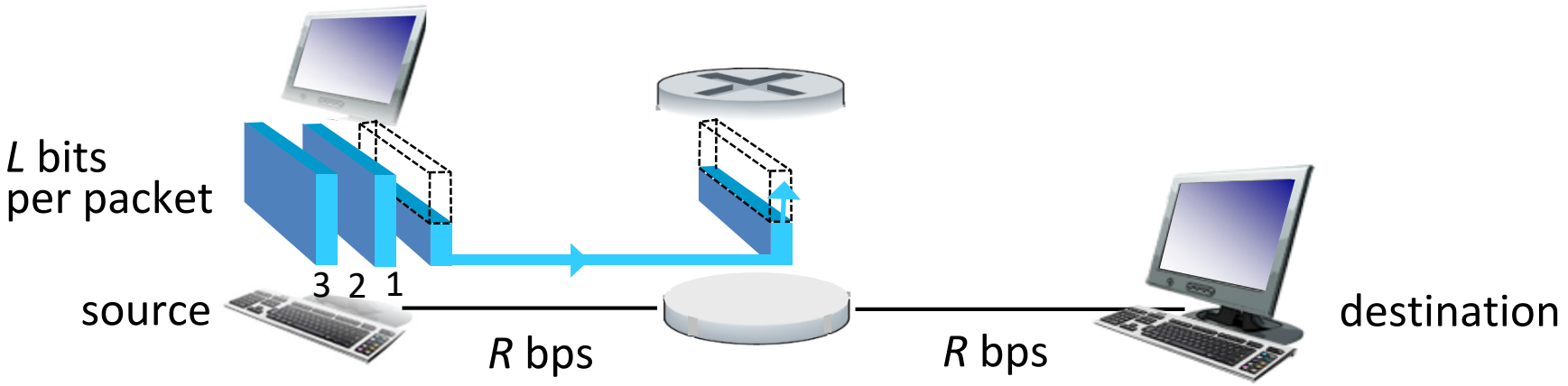
Routing


Victoria
Seattle
WASHINGTON
Portland
OREGON
IDAHO
NEVADA
UTAH
COLORADO
WYOMING
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
IOWA
45 h
3,053 miles
United States
routing
Minneapolis
WISCONSIN
MICHIGAN
Chicago
Detroit
Toronto
Ottawa
Montreal
Quebec City
MAINE
VERMONT
NEW HAMPSHIRE
Northampton
CT
RI
New York
PENNSYLVANIA
NJ
Philadelphia
MARYLAND
DE
WEST VIRGINIA
VIRGINIA
OHIO
INDIANA
ILLINOIS
Indianapolis
Kansas City
MISSOURI
KENTUCKY
Nashville
TENNESSEE
NORTH CAROLINA
Charlotte
SOUTH CAROLINA
Atlanta
GEORGIA
ALABAMA
MISSISSIPPI
ARKANSAS
OKLAHOMA
48 h
3,309 miles
Dallas
TEXAS
Houston
Austin
San Antonio
LOUISIANA
New Orleans
Jacksonville
Orlando
Tampa
FLORIDA
NEW MEXICO
ARIZONA
Phoenix
Tucson
El Paso
Las Vegas
Los Angeles
San Diego
CALIFORNIA
San Jose
San Francisco
Sacramento
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
Gulf of California

Forwarding


forwarding
forwarding
45 h
3,053 miles
48 h
3,309 miles
United States
Victoria
Seattle
Portland
WASHINGTON
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
Minneapolis
WISCONSIN
MICHIGAN
Toronto
Quebec City
Montreal
Ottawa
MAINE
VERMONT
NEW HAMPSHIRE
Northampton
Detroit
Chicago
WYOMING
IOWA
ILLINOIS
INDIANA
OHIO
Kansas City
Indianapolis
COLORADO
KANSAS
MISSOURI
KENTUCKY
Nashville
TENNESSEE
San Francisco
San Jose
CALIFORNIA
Las Vegas
OKLAHOMA
ARKANSAS
Los Angeles
ARIZONA
NEW MEXICO
Phoenix
San Diego
Tucson
El Paso
Dallas
Atlanta
MISSISSIPPI
ALABAMA
TEXAS
BAJA CALIFORNIA
SONORA
CHIHUAHUA
Austin
Houston
San Antonio
LOUISIANA
New Orleans
COAHUILA
Tampa
FLORIDA
Cleveland
DOWNTOWN
CENTRAL
OHIO CITY

Packet-switching: store-and-forward

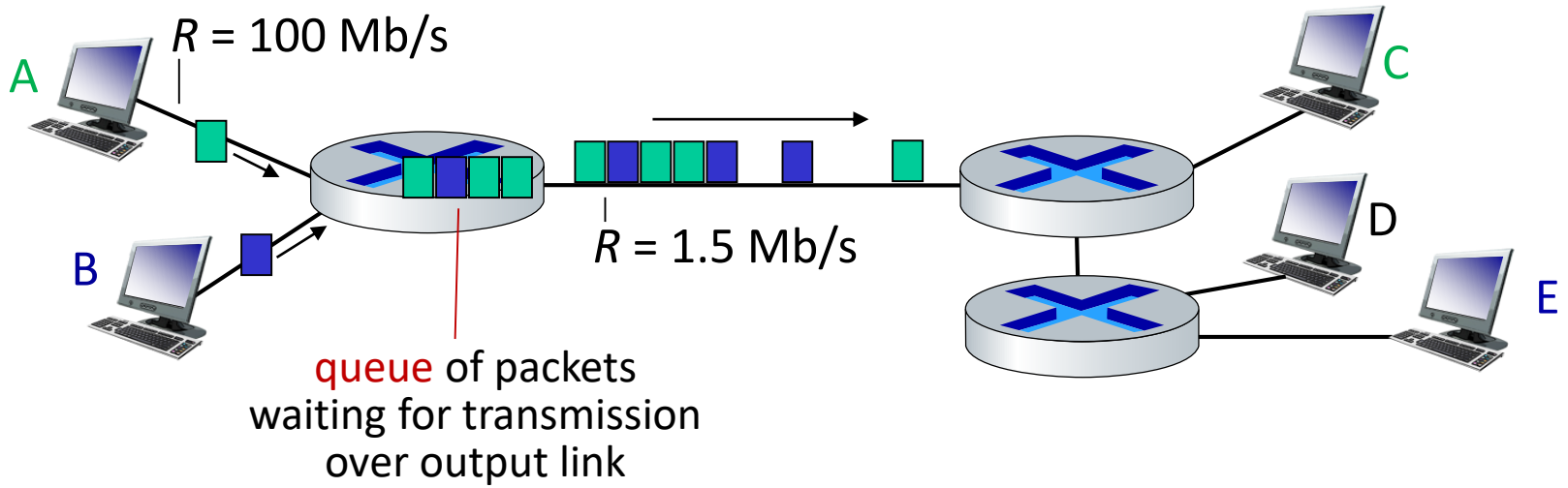


- packet transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward: entire* packet must arrive at router before it can be transmitted on next link

One-hop numerical example:

- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing

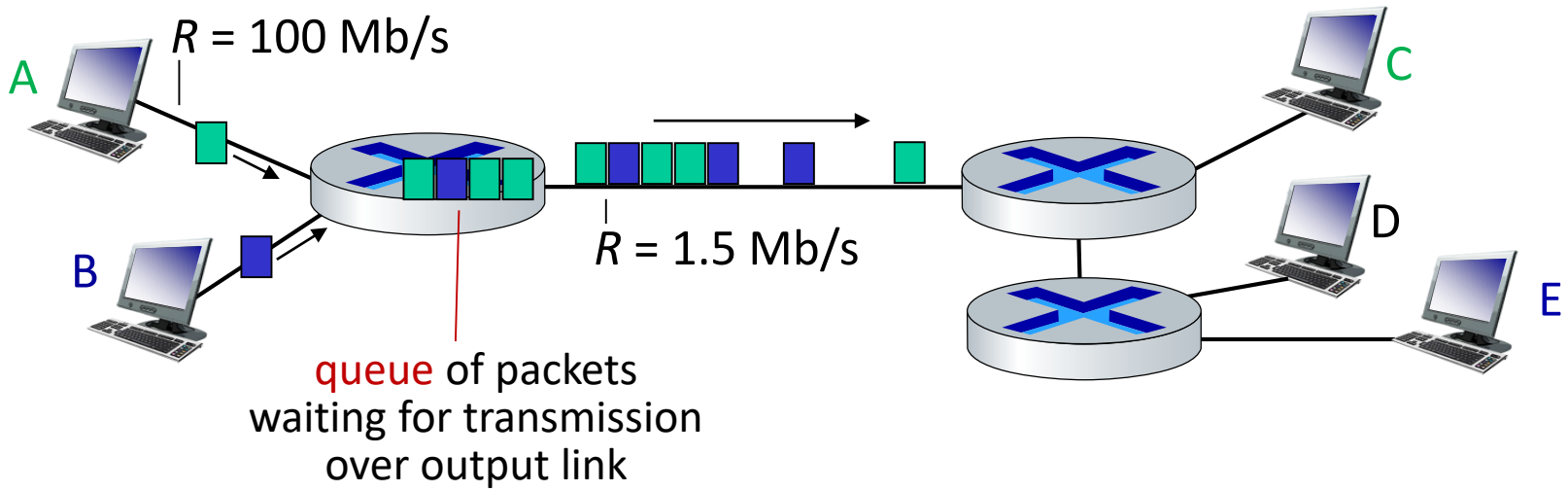


Queueing occurs when work arrives faster than it can be serviced:

Packet-switching: queueing

In the context of Queuing System

- arrival rate is λ
- service rate is μ



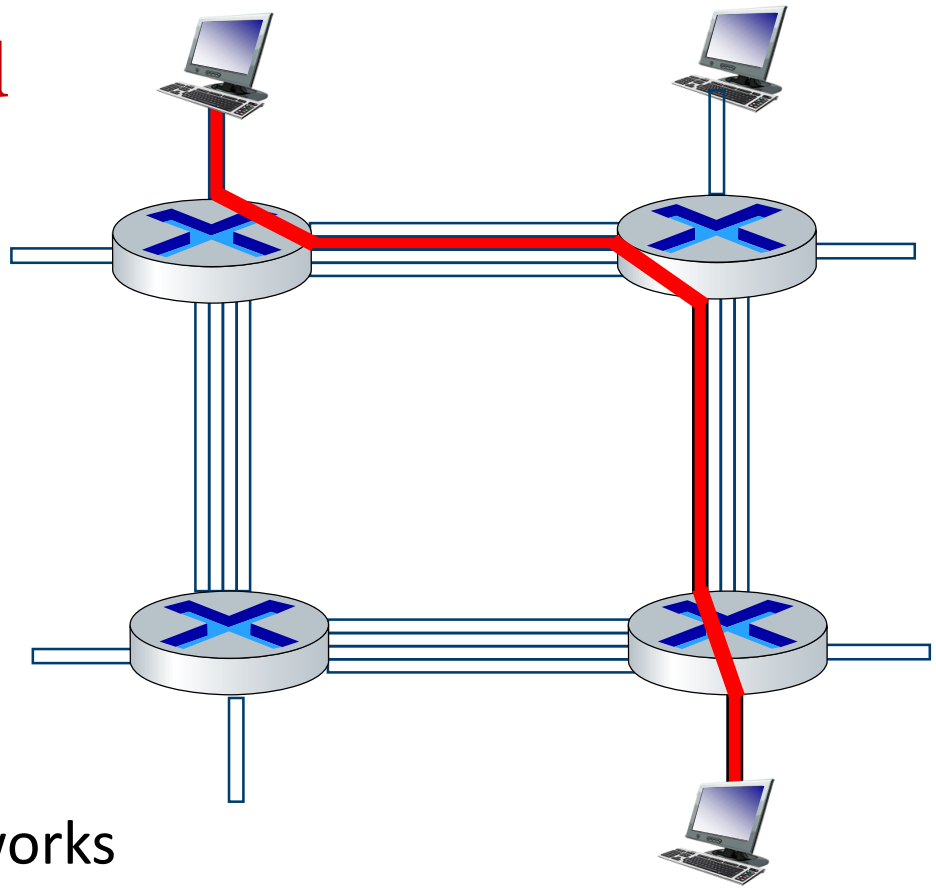
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Alternative to packet switching: circuit switching

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

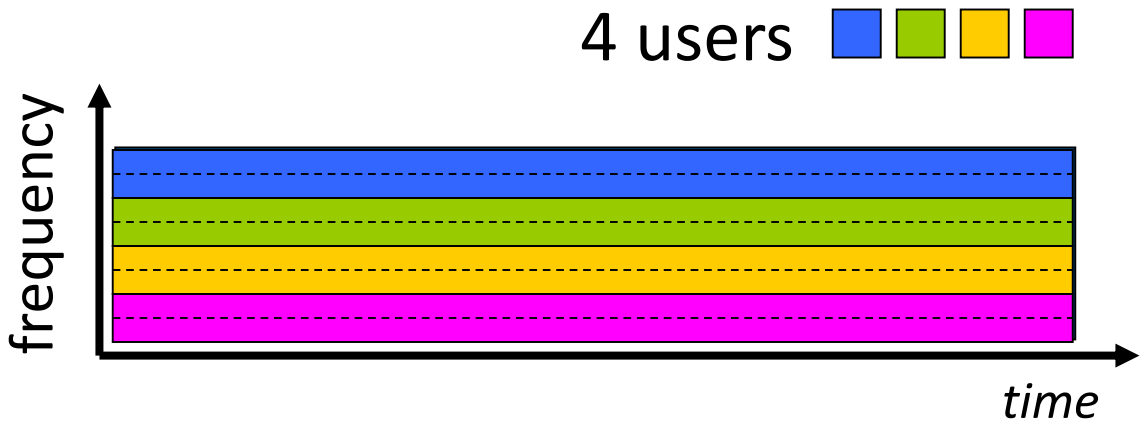
- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
  - commonly used in traditional telephone networks



Circuit switching: FDM and TDM

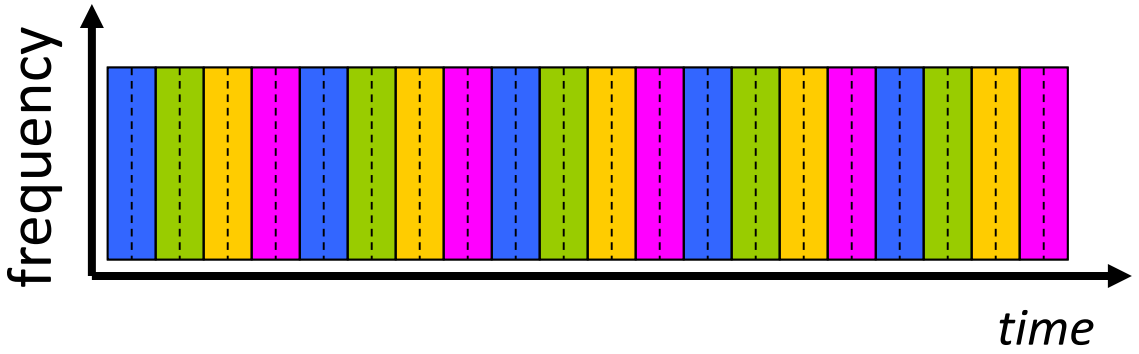
Frequency Division Multiplexing

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band



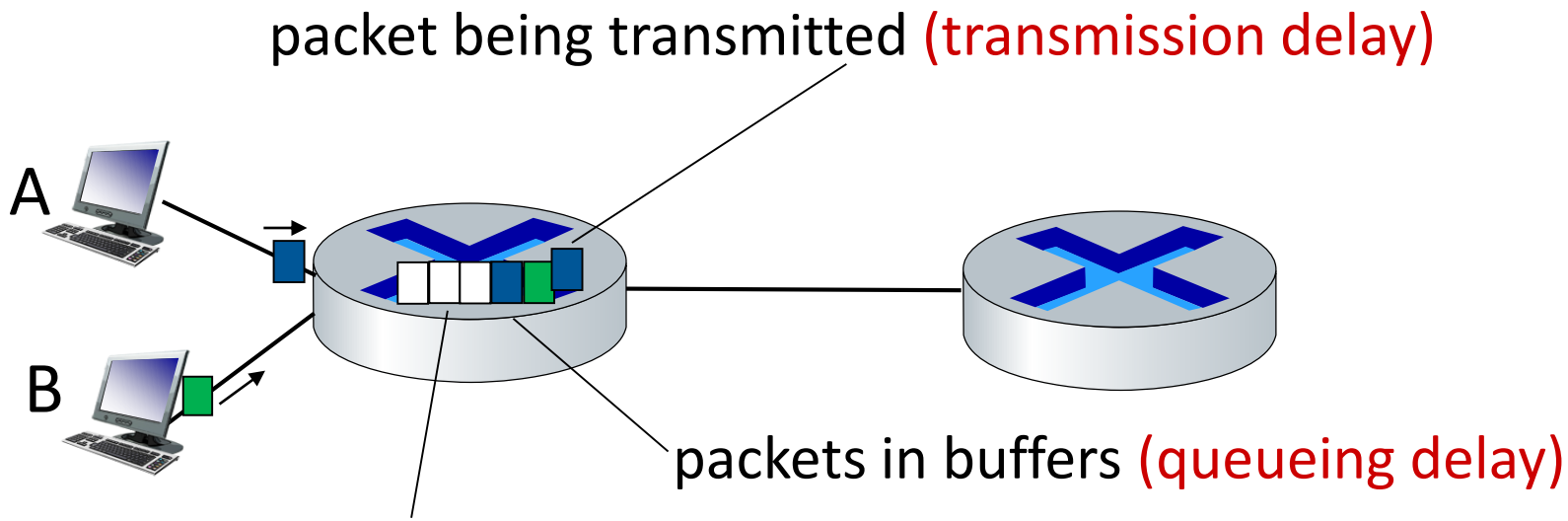
Time Division Multiplexing

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)

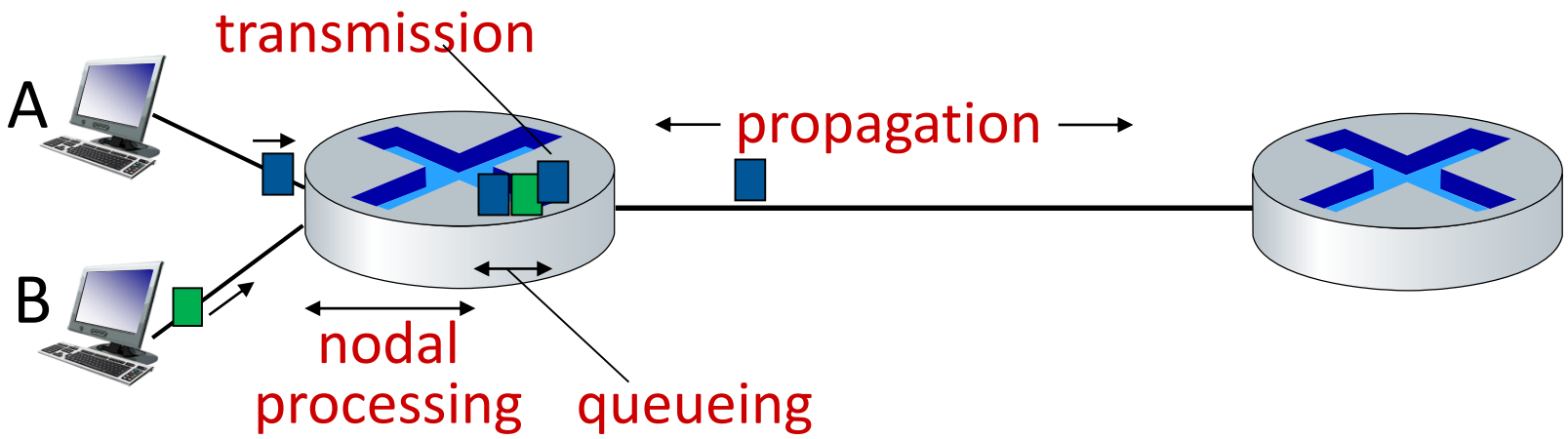


How do packet delay and loss occur?

- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up



Packet delay: four sources



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

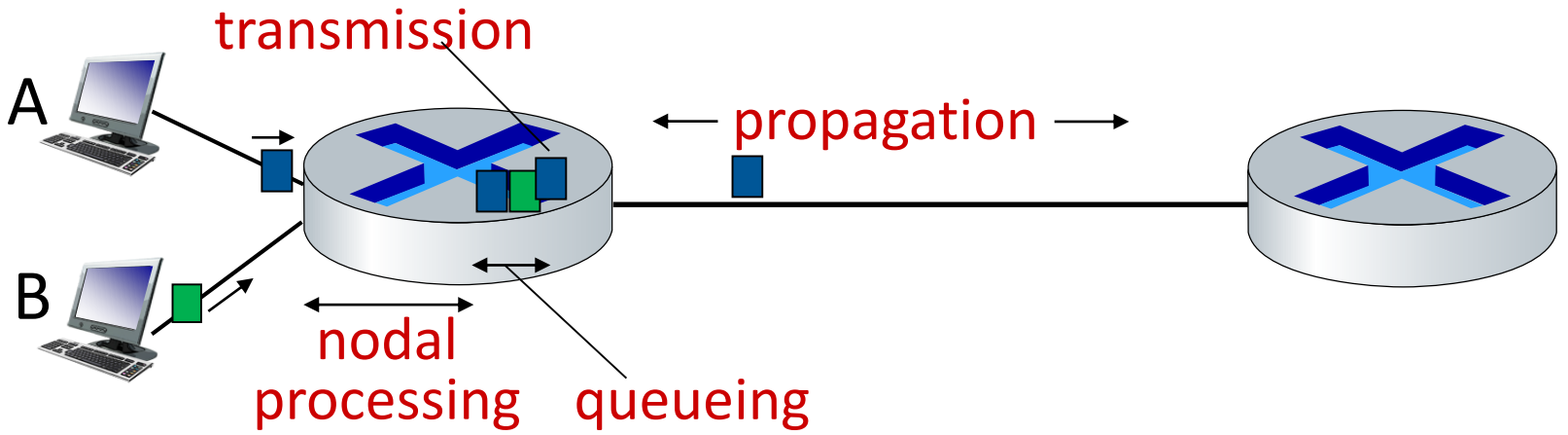
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < microsecs

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Packet delay: four sources



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

d_{trans}: transmission delay:

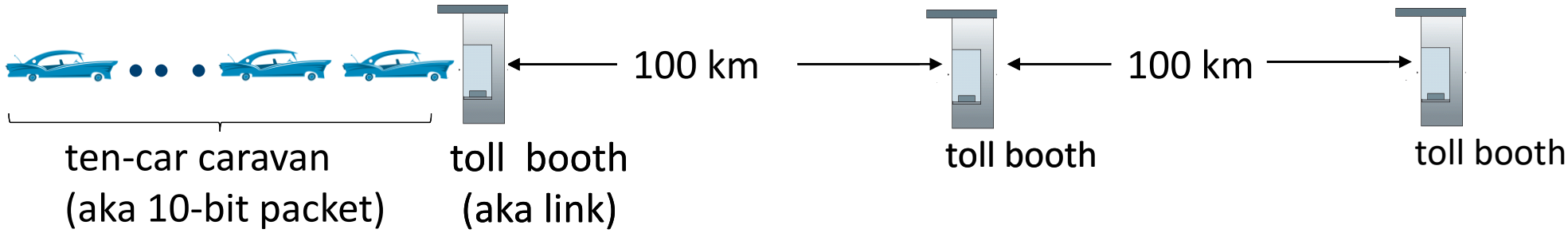
- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed (~2×10^8 m/sec)
- $d_{prop} = d/s$

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

Caravan analogy

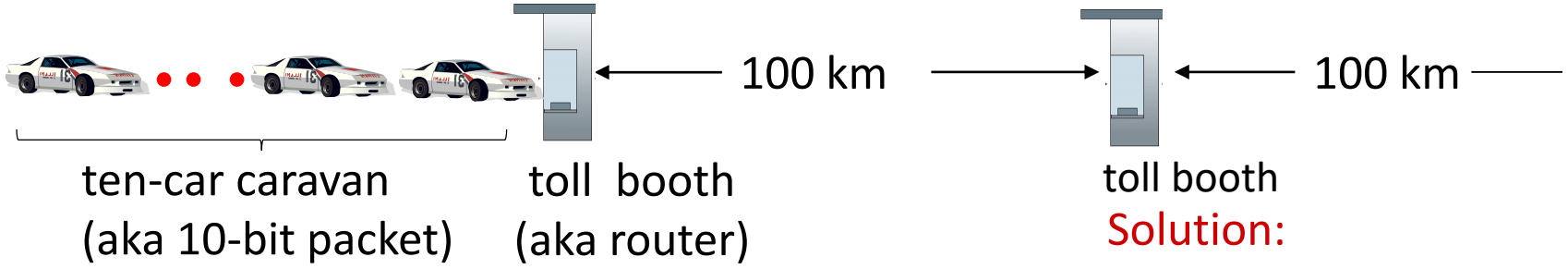


- car ~ bit; caravan ~ packet; toll service ~ link transmission
- toll booth takes 12 sec to service car (bit transmission time)
- "propagate" at 100 km/hr
- *Q:* How long until caravan is lined up before 2nd toll booth?

Solution:

- 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/hr) = 1 hr
- *A:* 62 minutes

Caravan analogy



Solution:

- time to "push" one car through toll booth onto highway = 60*1 = 60 sec
- time for first car to propagate toll booth: 100km/(1000km/hr) = 0.1 hr

- suppose cars now "propagate" at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?

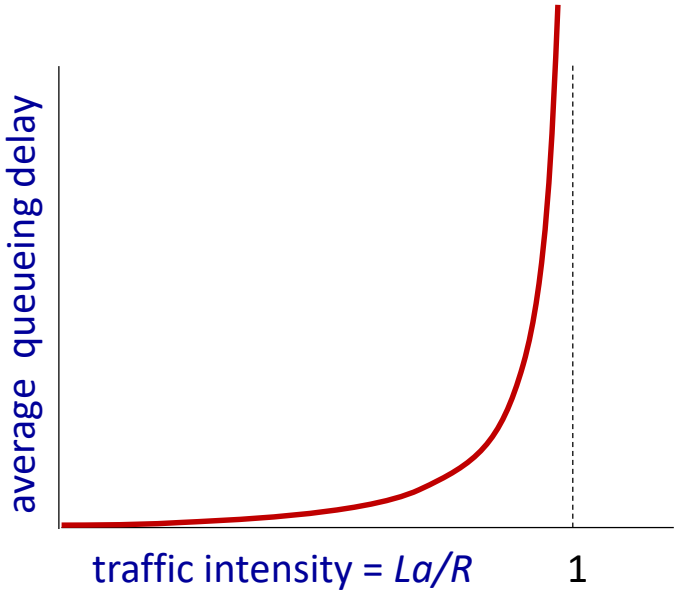
A: Yes! after 7 min, first car arrives at second booth; three cars still at first booth

Packet queueing delay (revisited)

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

$$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$

"traffic intensity"



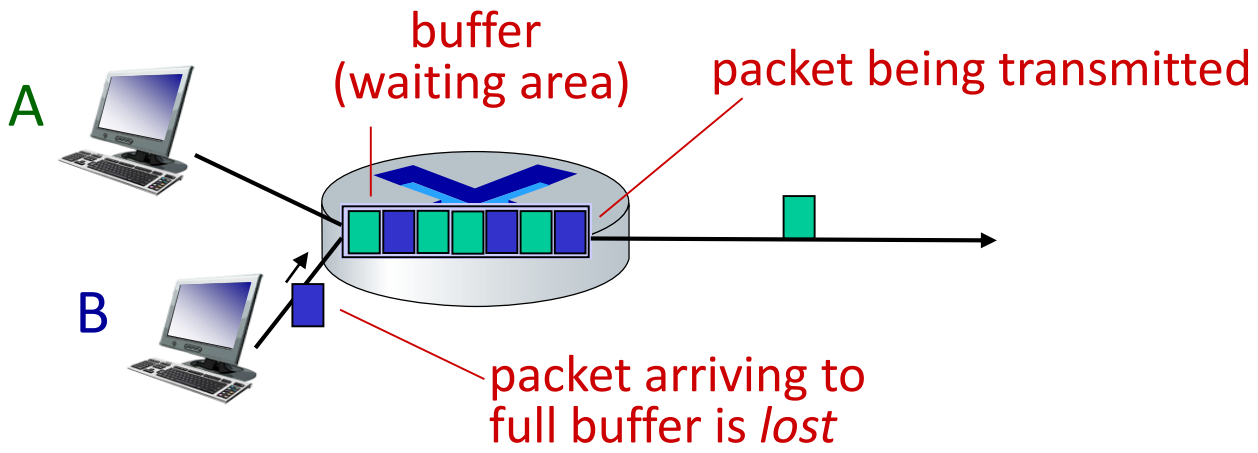
- *La/R* ~ 0: avg. queueing delay small
- *La/R* < 1: avg. queueing delay large
- *La/R* => 1: more "work" arriving is more than can be serviced - average delay infinite!

La/R ~ 0

La/R => 1

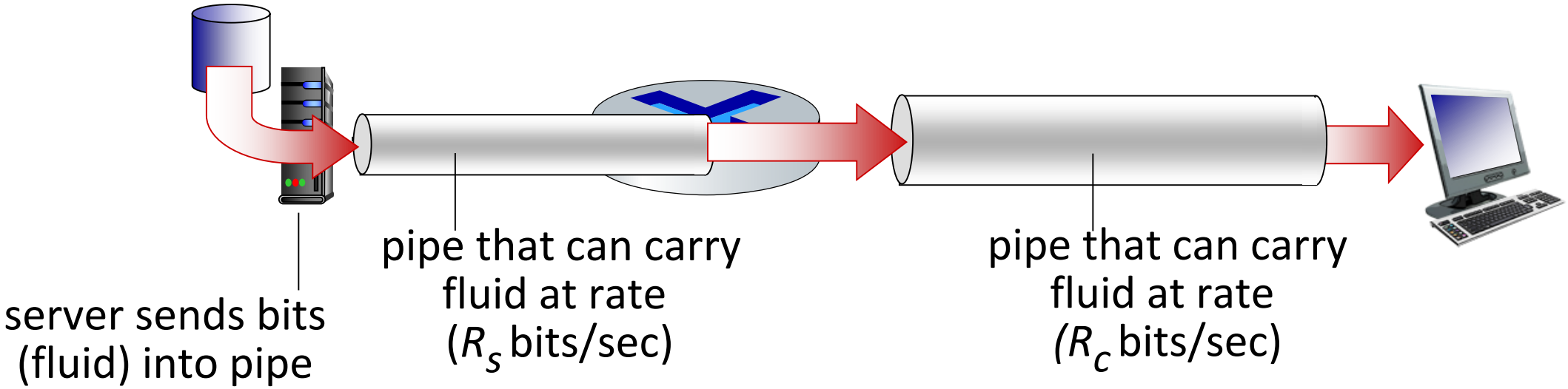
Packet loss

- 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

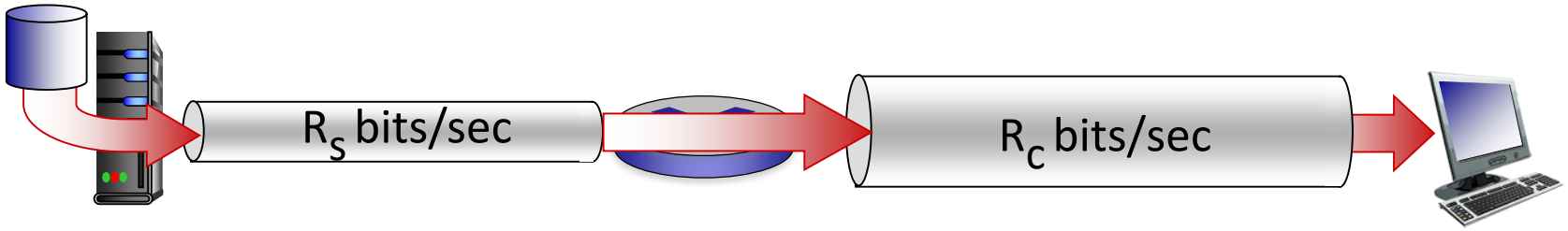
- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



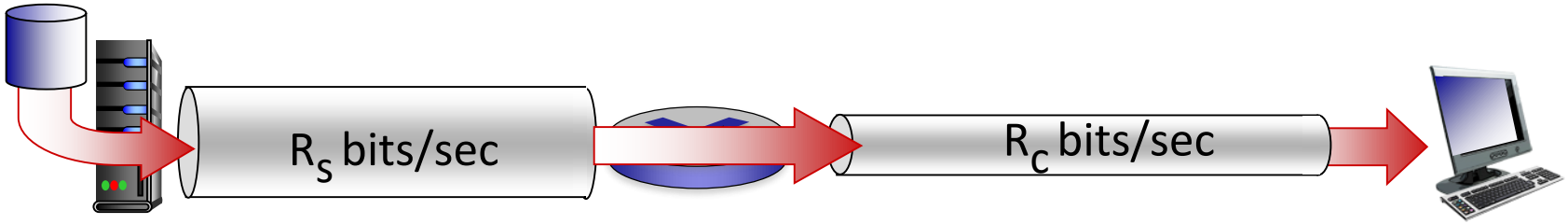
Throughput

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

$\min\{R_s, R_c\}$



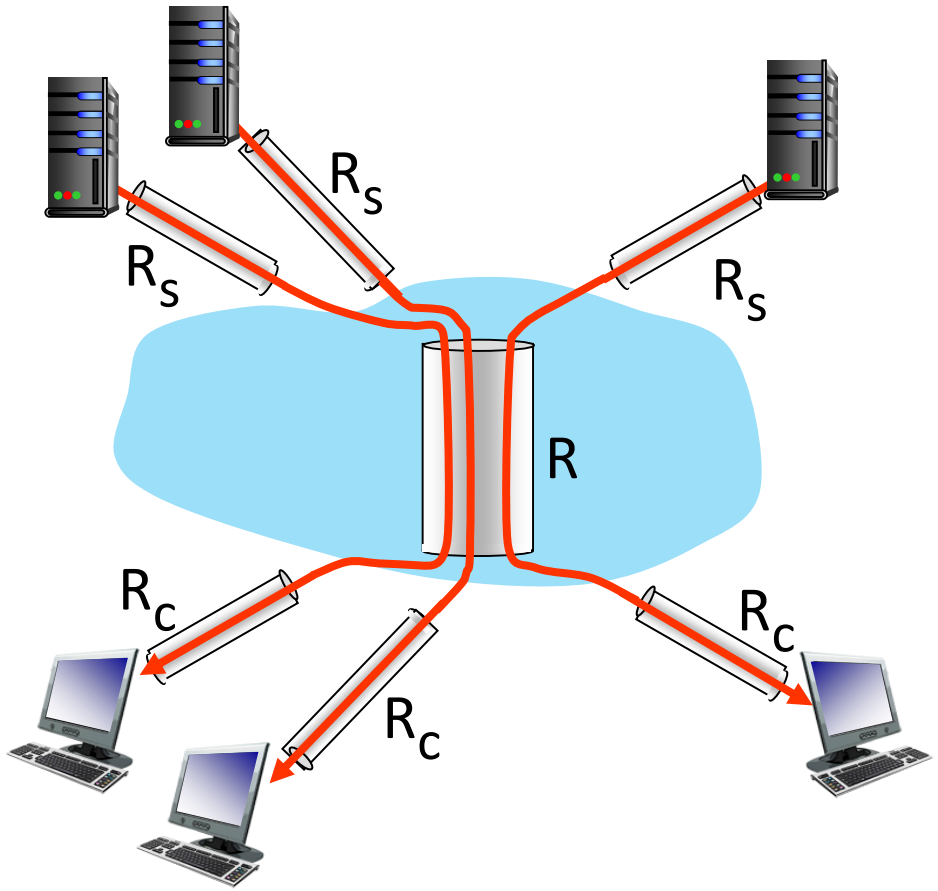
$R_s > R_c$ What is average end-end throughput?



bottleneck link

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

Throughput: network scenario



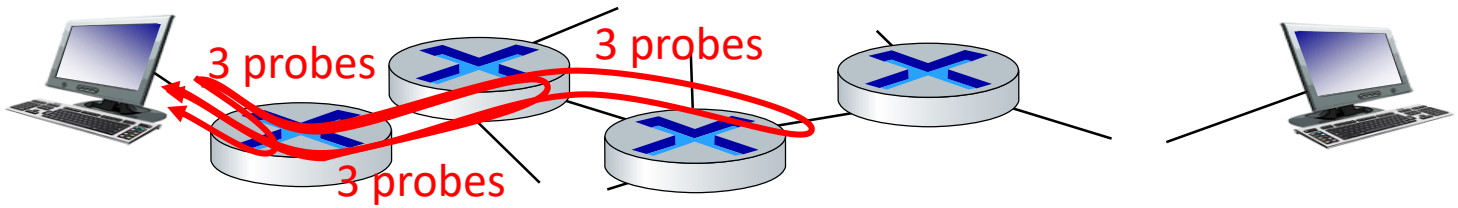
10 connections (fairly) share backbone bottleneck link *R* bits/sec

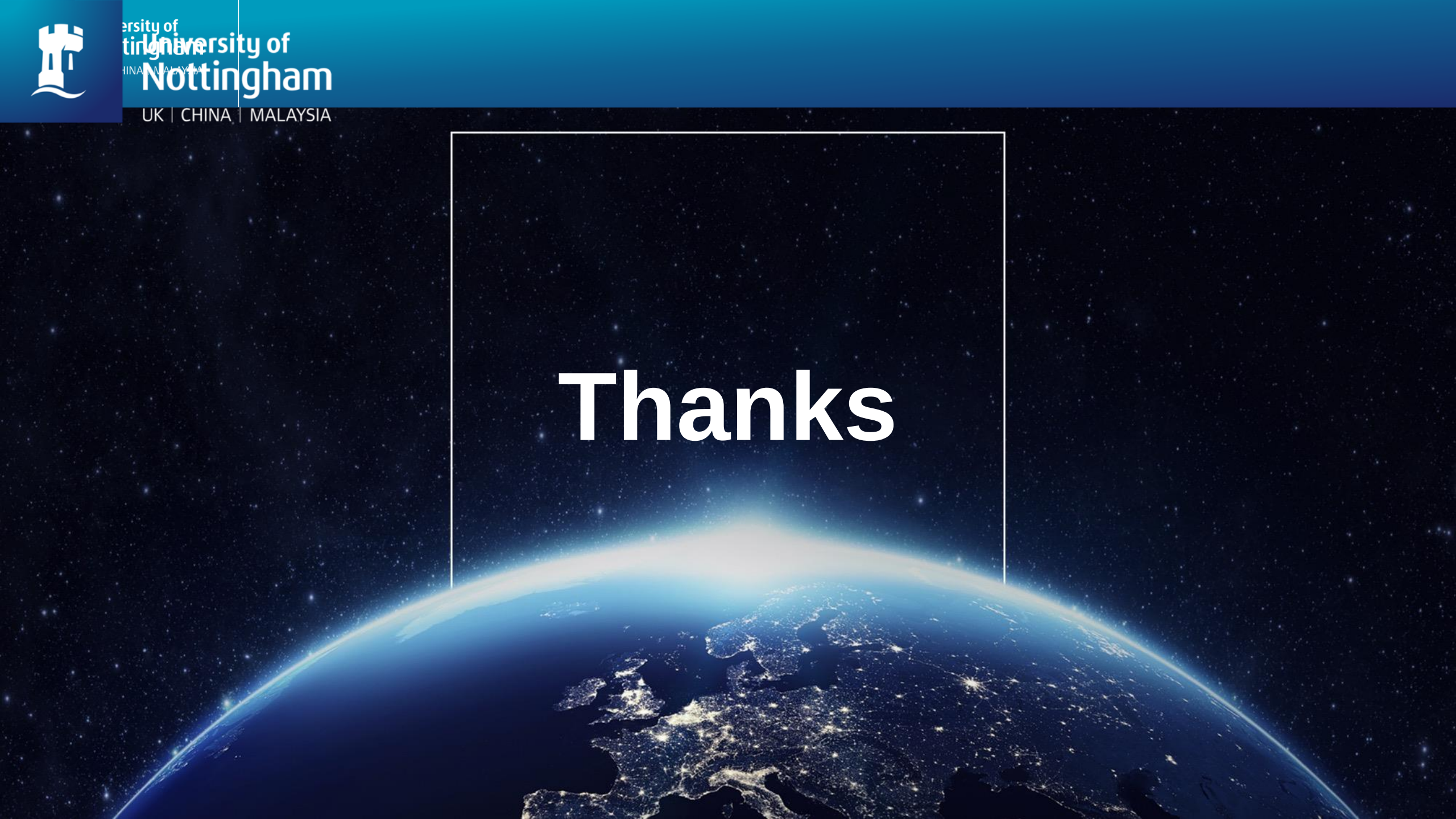
- per-connection end-end throughput: *min(R_c,R_s, R/10)*
- in practice: R_c or R_s is often bottleneck

“Real” Internet delays and routes

Tracert command

- 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 (with time-to-live field value of *i*)
  - router *i* will return packets to sender
  - sender measures time interval between transmission and reply

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Thanks