

# Introduction

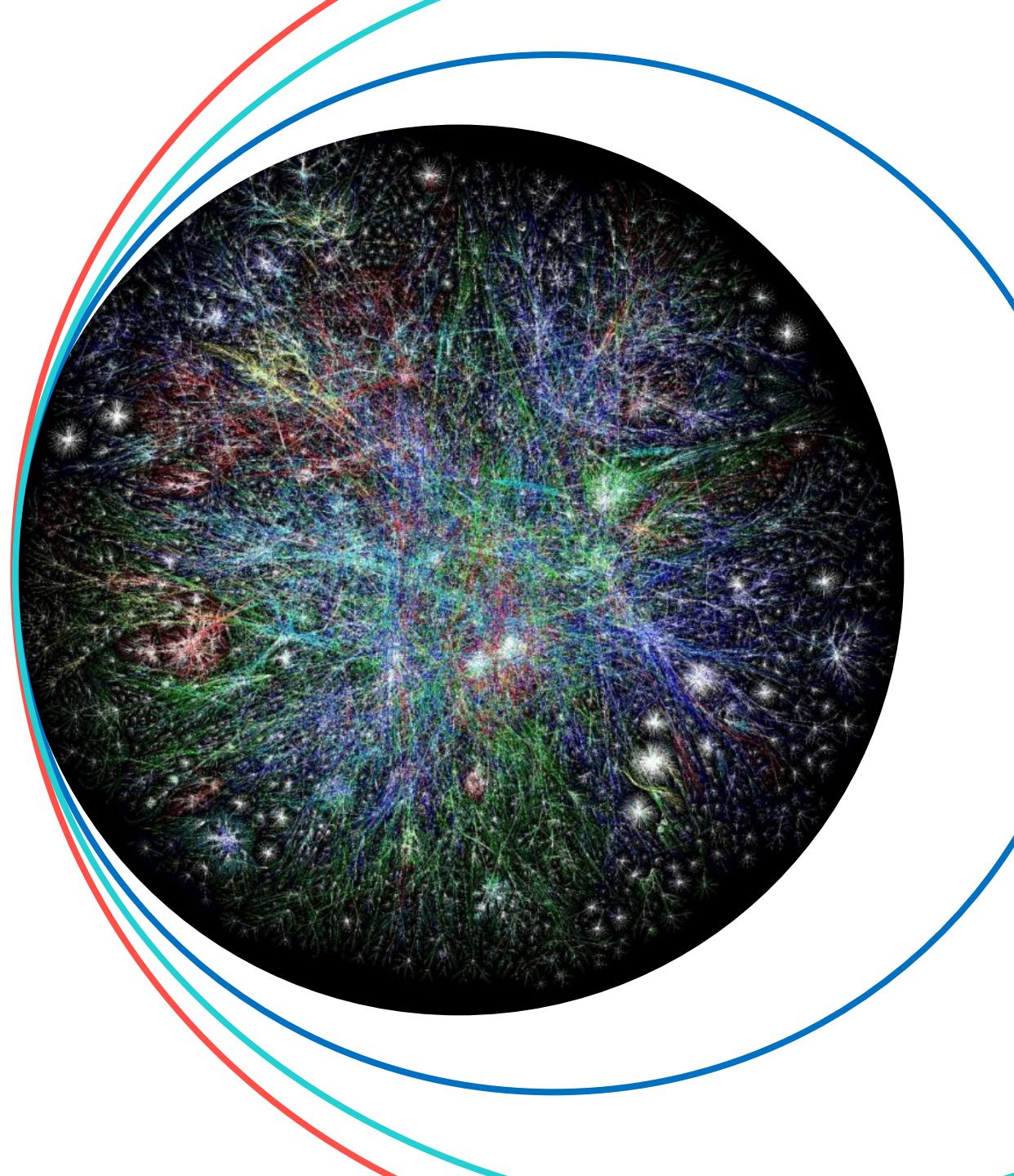


# Introduction

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- The Internet
- Basics
  - Network Edge
  - Network Core
  - Network Performance
    - Loss, Bandwidth, Throughput, Latency, Delay, Jitter
- Protocol Layers and Reference Models
- Network Security: Networks Under Attack
- Brief History of Networking

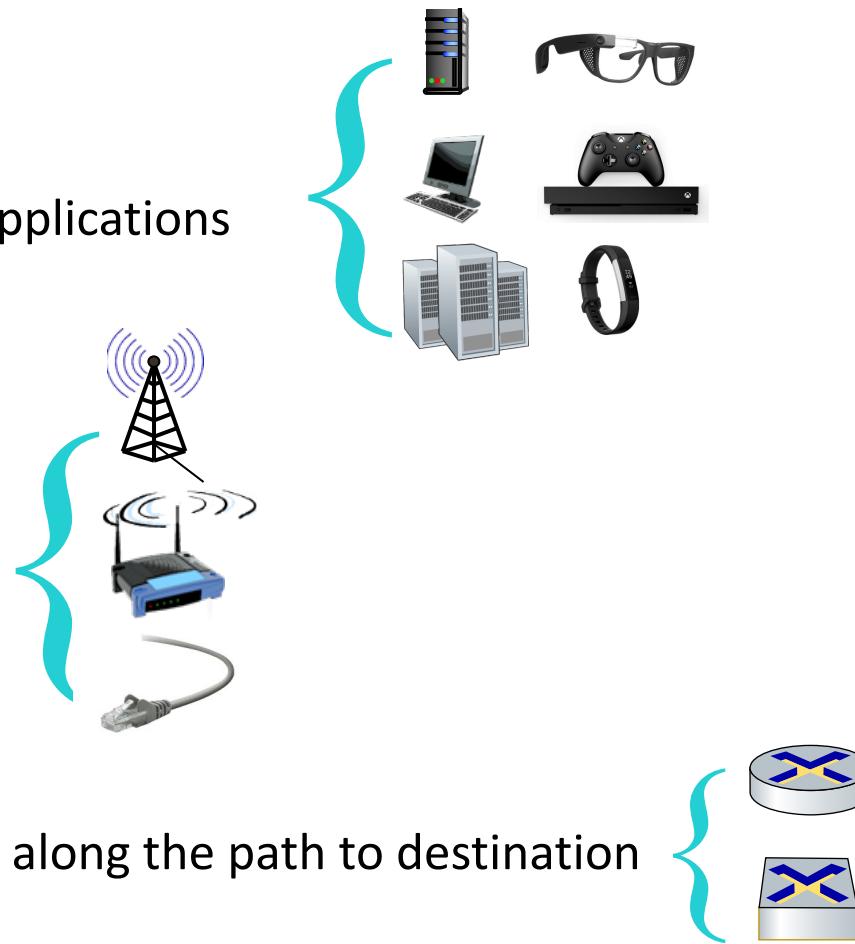
# Introduction: The Internet



# The Internet

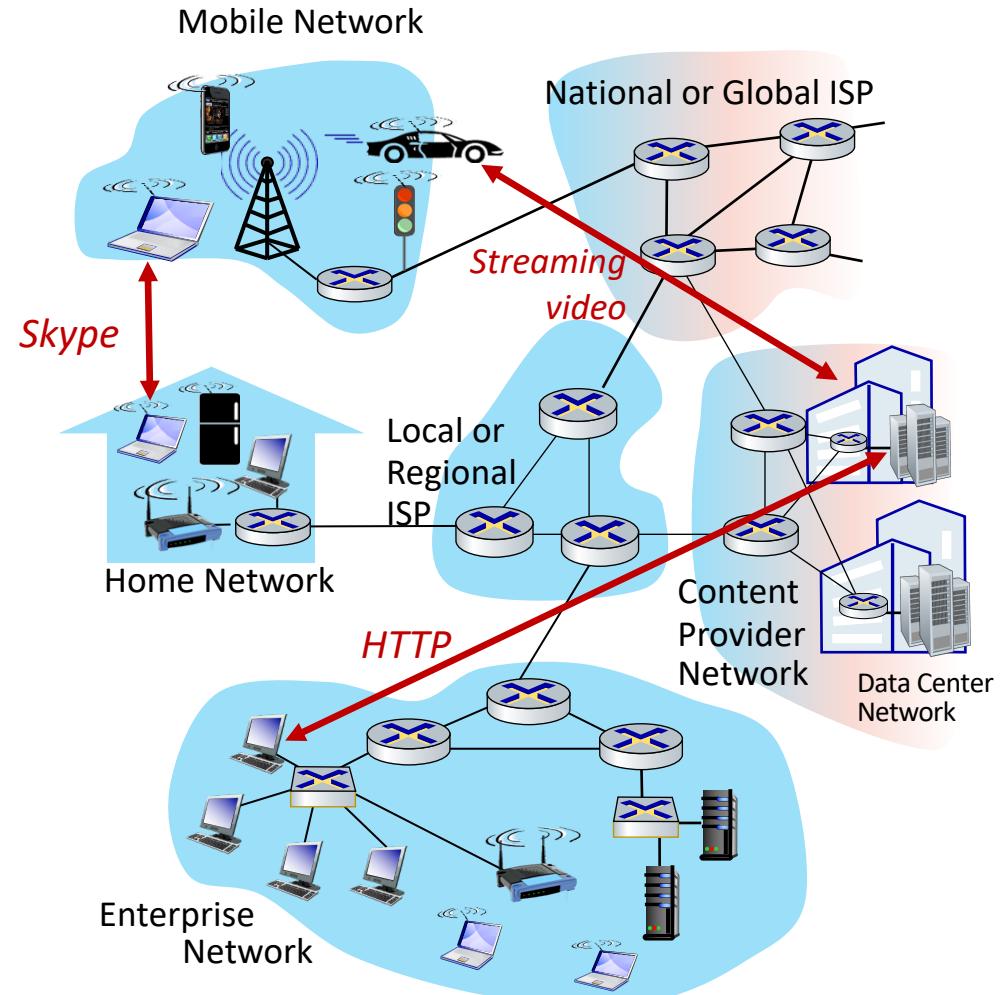
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- Nuts and Bolts
  - Hosts
    - **End systems** running network applications
  - Communication Links
    - Fiber, Copper, Radio, Satellite
  - Switches and Routers
    - Find other switches and routers along the path to destination and forward data



# The Internet

- Network of networks:  
Interconnected ISPs
  - Infrastructure providing **service** to applications
  - Infrastructure providing **programming interfaces (Socket Interface)** to applications

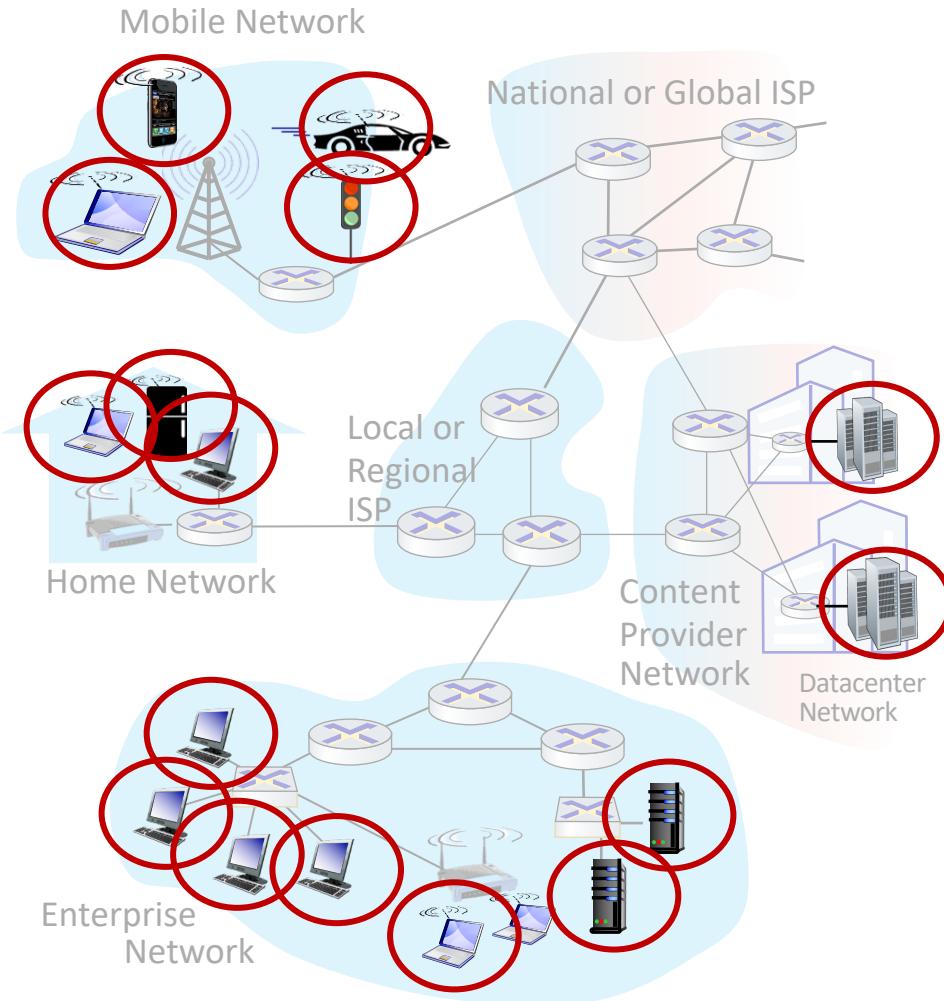


# Introduction: Network Edge



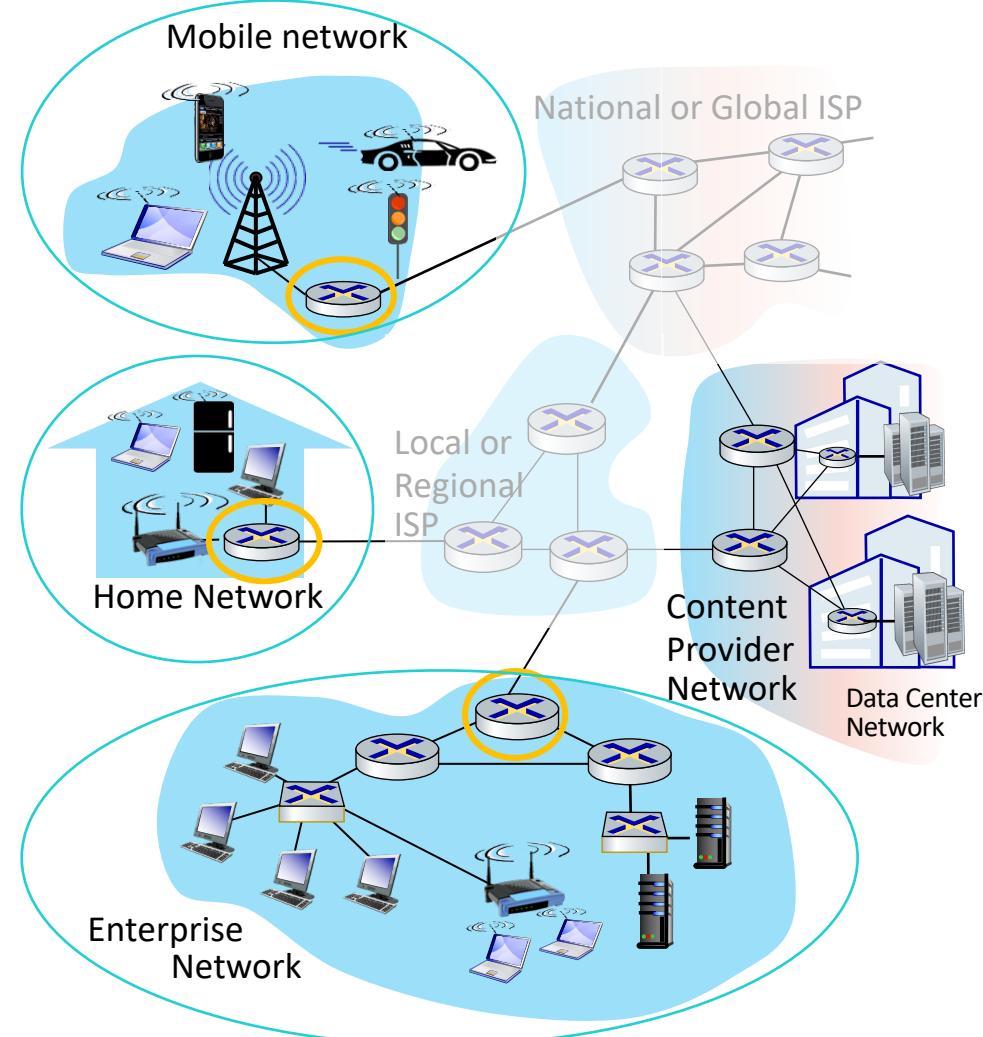
# Network Edge

- Network Edge: Includes end systems
- Access Network



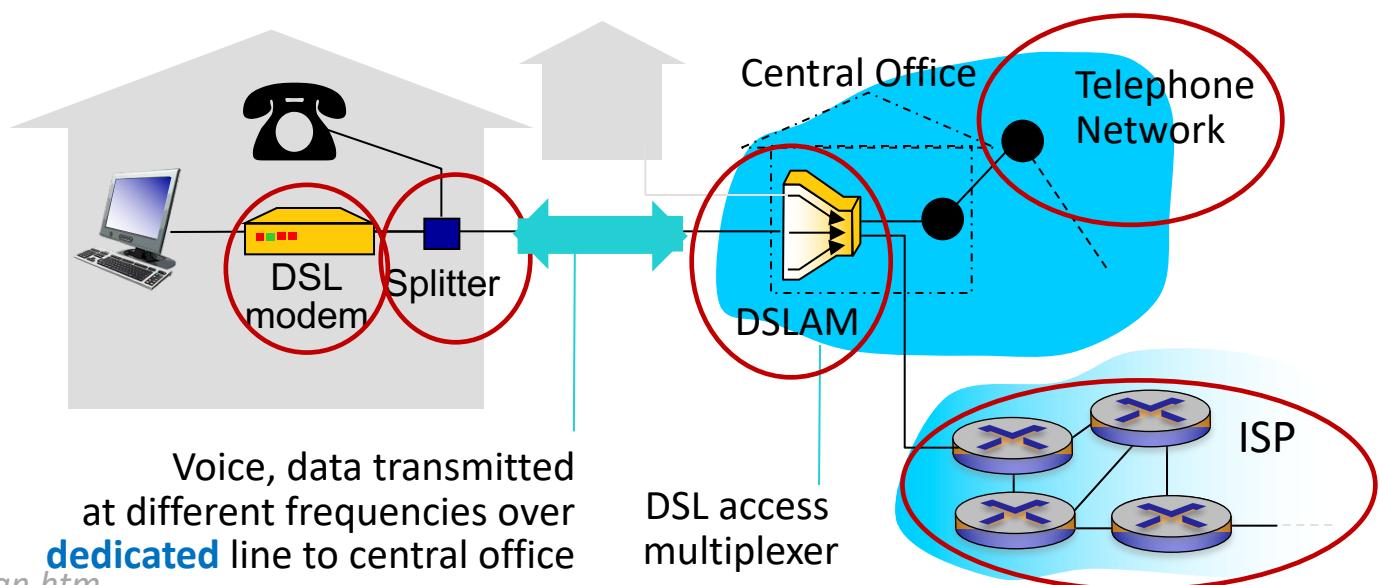
# Network Edge

- Network Edge: Includes end systems
- Access Network
  - Connecting **End systems** to **Edge Routers**
  - Access
    - Digital Subscriber Line (DSL)
    - Cable
    - **Fiber**, Fiber To The Home (FTTH)
    - Dial-up
    - Satellite
  - Home Access
    - WiFi
  - Enterprise Access
    - WiFi
    - Ethernet
  - Mobile & Wide-Area Wireless Access
    - 3G
    - Long Term Evolution (LTE)
    - 5G



# Access Networks: DSL

- Digital Subscriber Line (DSL)
  - Uses **pre-existing** telephone line to central office DSLAM
    - Data over DSL phone line goes to Internet
    - Voice over DSL phone line goes to telephone net

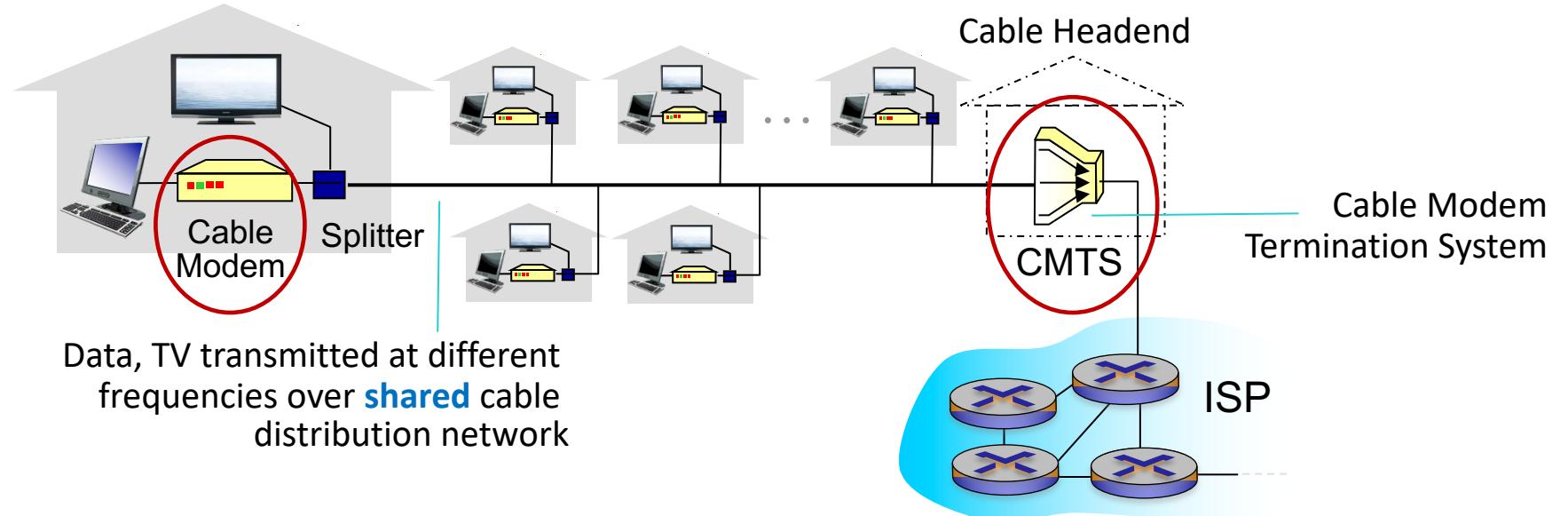


<https://crtc.gc.ca/eng/publications/reports/PolicyMonitoring/ban.htm>

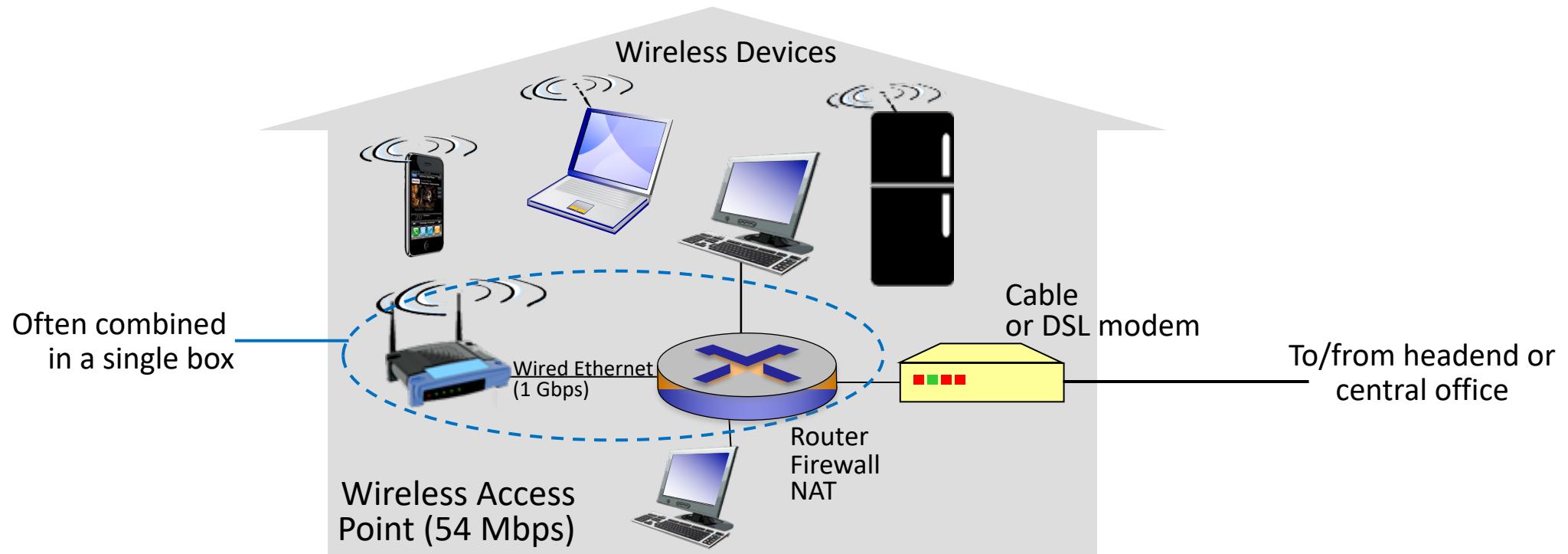
<https://ised-isde.canada.ca/app/scr/sittibc/web/bbmap#!/map>

# Access Networks: Cable Network

- **HFC (Hybrid Fiber Coax)**: Asymmetric
- **FDM (Frequency Division Multiplexing)**: Different channels transmitted in different frequency bands
- **Network** of cables and fibers attaches homes to ISP router
  - Homes **share access network** to cable headend
  - Unlike DSL, which has dedicated access to central office

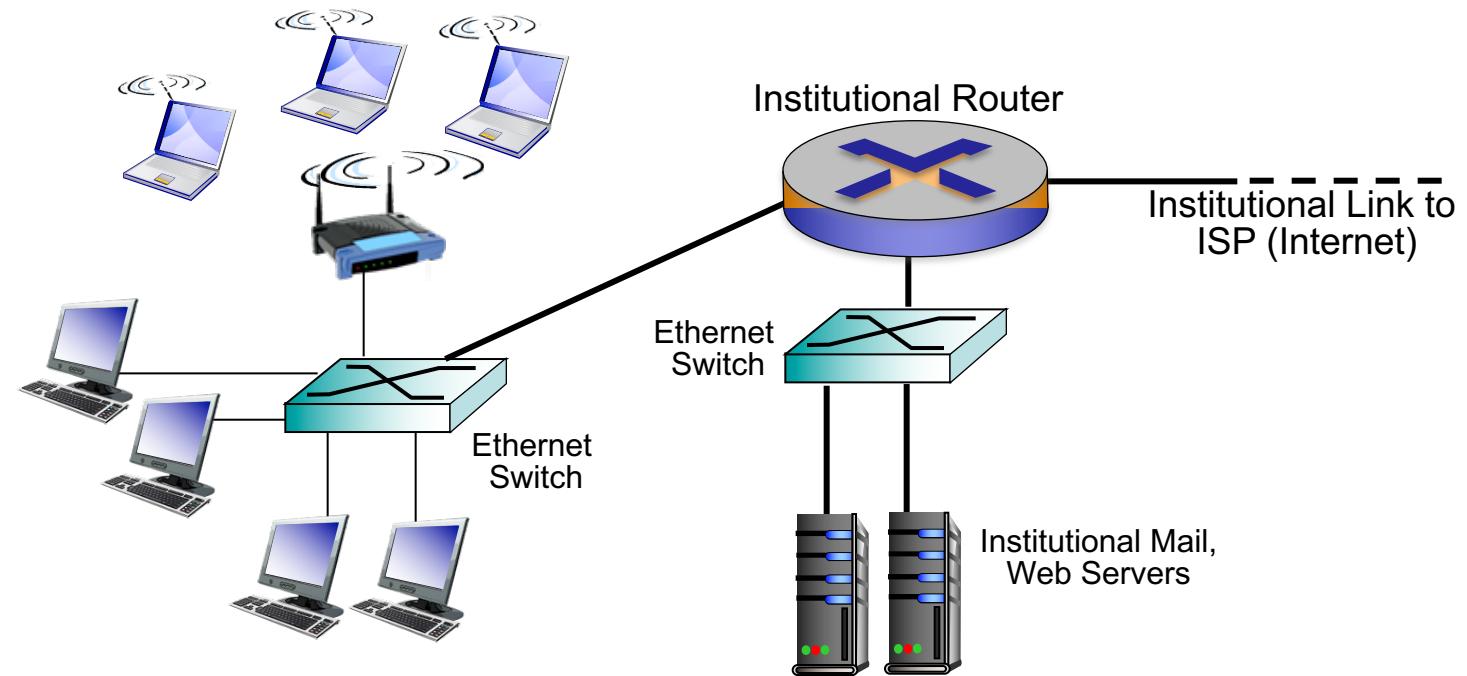


# Access Networks: Home Networks



# Access Networks: Enterprise Access

- Ethernet
  - Typically used in companies, universities, etc.
  - End systems typically connect into Ethernet switch

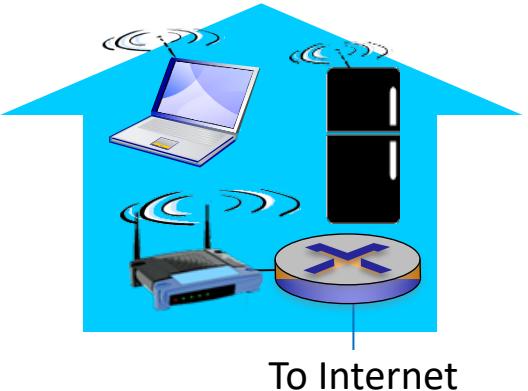


# Wireless Access Networks

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- Wireless Local Access Networks (LANs)

- Shared **wireless** access network connects end system to router (through access point)
- Within building
- 802.11b/g/n/ac/ax (WiFi)



- Wide-Area Wireless Access (WANs)

- Provided by telco (cellular) operator
- 3G, 4G/LTE, 5G



# Access Media

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- Physical Media

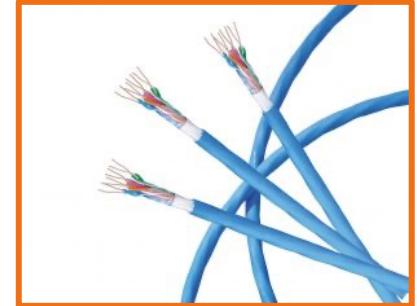
- Guided Media

- Twisted-Pair Copper Wire  
Two insulated copper wires



- Coaxial Cable

- Two concentric copper conductors  
Bidirectional  
Broadband (multiple channels on cable, HFC)



- Fiber Optics

- Glass fiber carrying light pulses, each pulse a bit  
High-speed point-to-point transmission  
Low error rate: repeaters spaced far apart, immune to electromagnetic noise



- Unguided Media

# Access Media

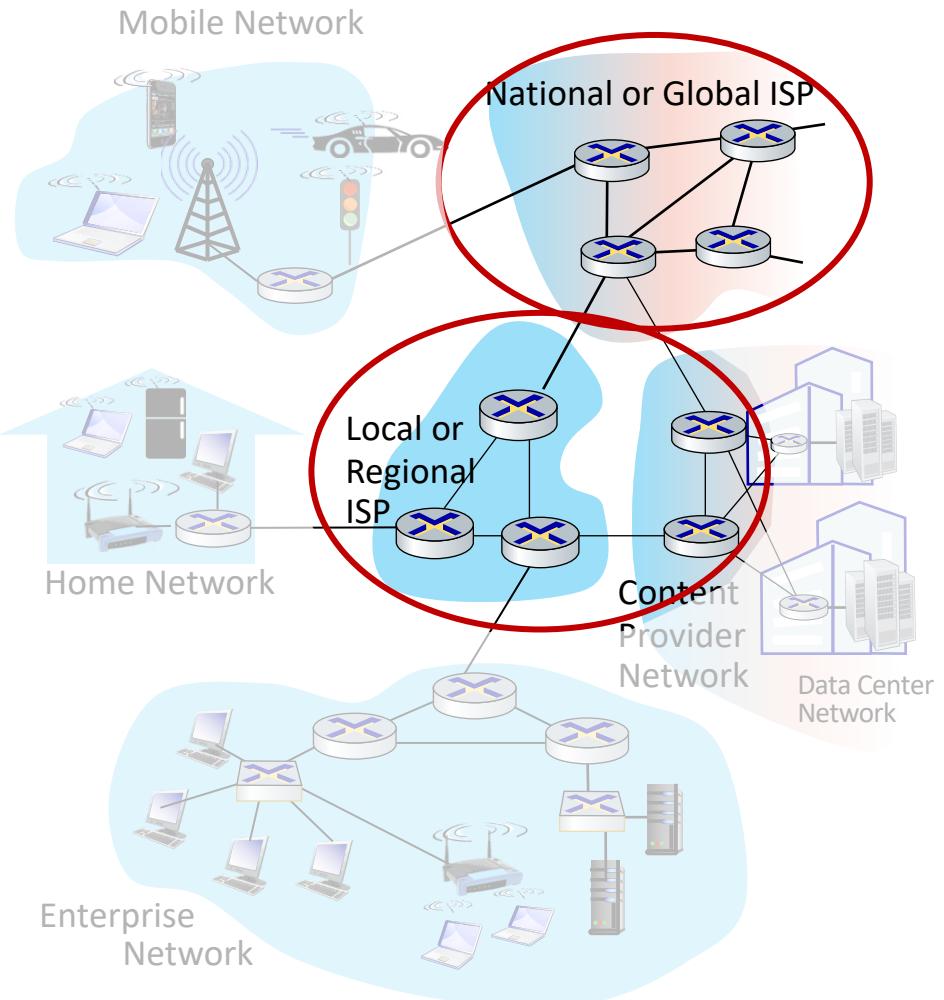
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- Physical Media
  - Guided Media
  - **Unguided Media**
    - Radio (No wire, Bidirectional)
      - Propagation Environment Effects
        - Reflection
        - Obstruction by objects
        - Interference
      - Radio Link Types
        - Terrestrial Microwave
          - Personal Area
          - Local Area
          - Wide Area
        - Satellite Radio Channels
          - Geosynchronous versus low altitude

# Introduction: Network Core

# Network Core

- Connect the access networks
  - Mesh of interconnected routers
  - Providing a path between source and destination through shared network resources
    - **Packet Switching**
    - Circuit Switching



# Circuit Switching

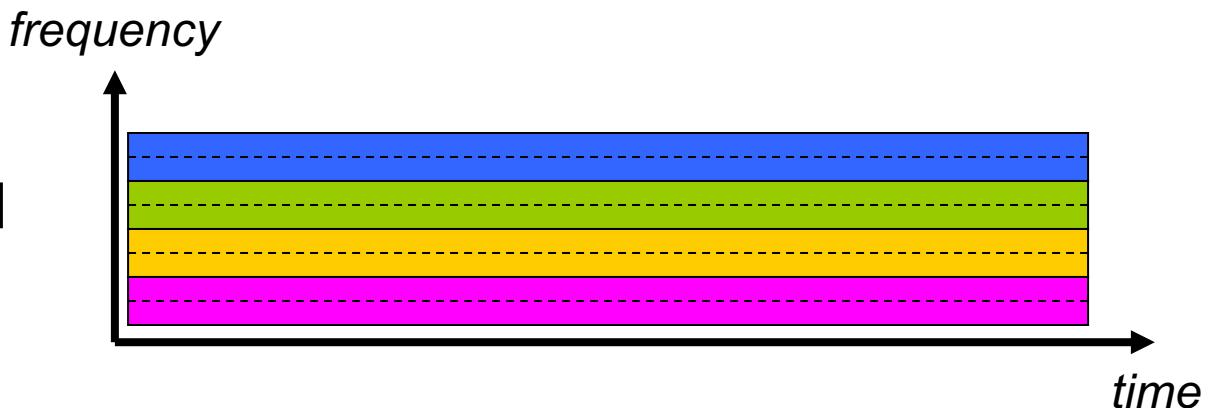
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- End to end resources reserved and allocated between source and destination
  - **FDM:** Frequency-Division Multiplexing
    - Frequency spectrum of a link is divided among the connections
  - **TDM:** Time-Division Multiplexing
    - Users time share by receiving a dedicated fix-length time slot in a time frame

# Circuit Switching: FDM & TDM

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Figure (1): **FDM**

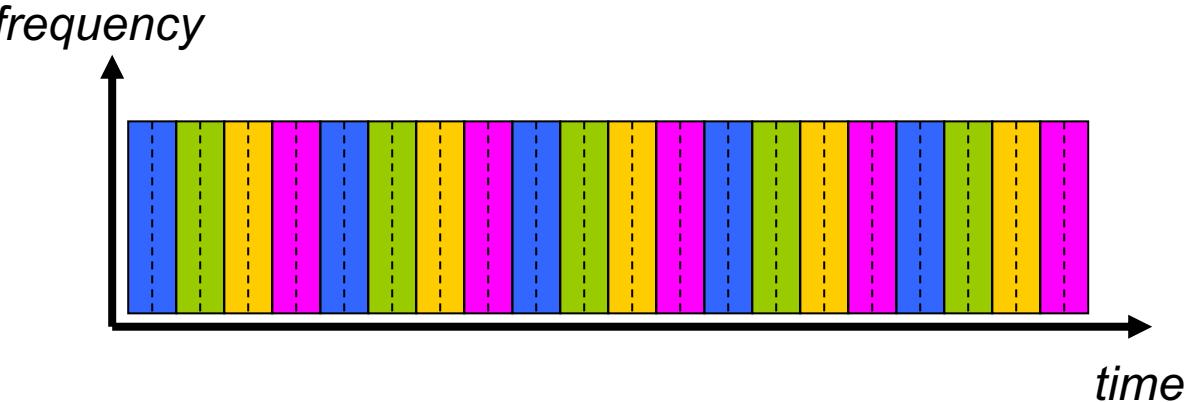


**Example:**

Four users

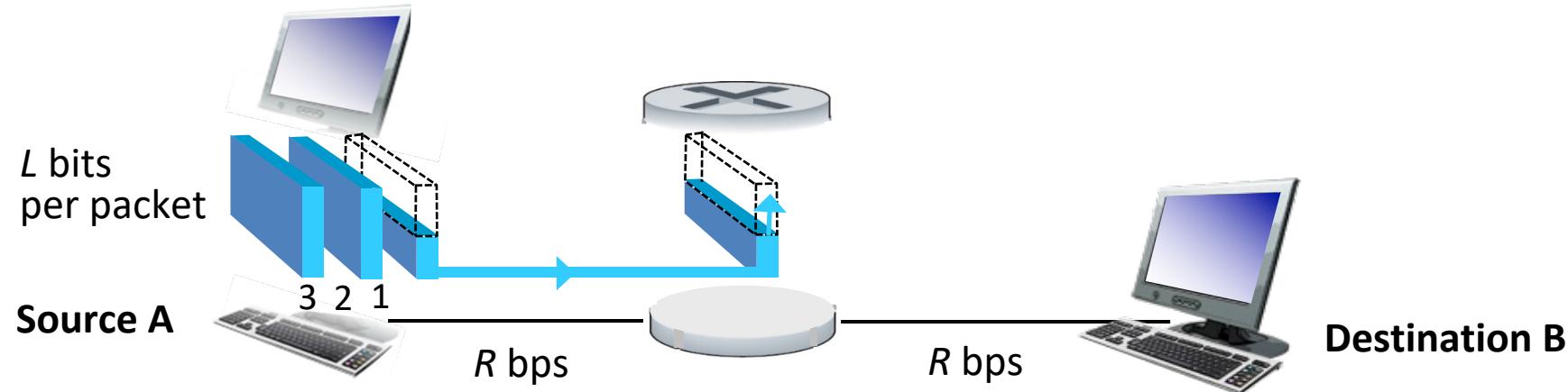
1 2 3 4

Figure (2): **TDM**



# Packet Switching: Store & Forward

- **Packet Switching:** Store-and-forward a chunk of data called packet



Entire packet must arrive at router before it can be transmitted on the next link

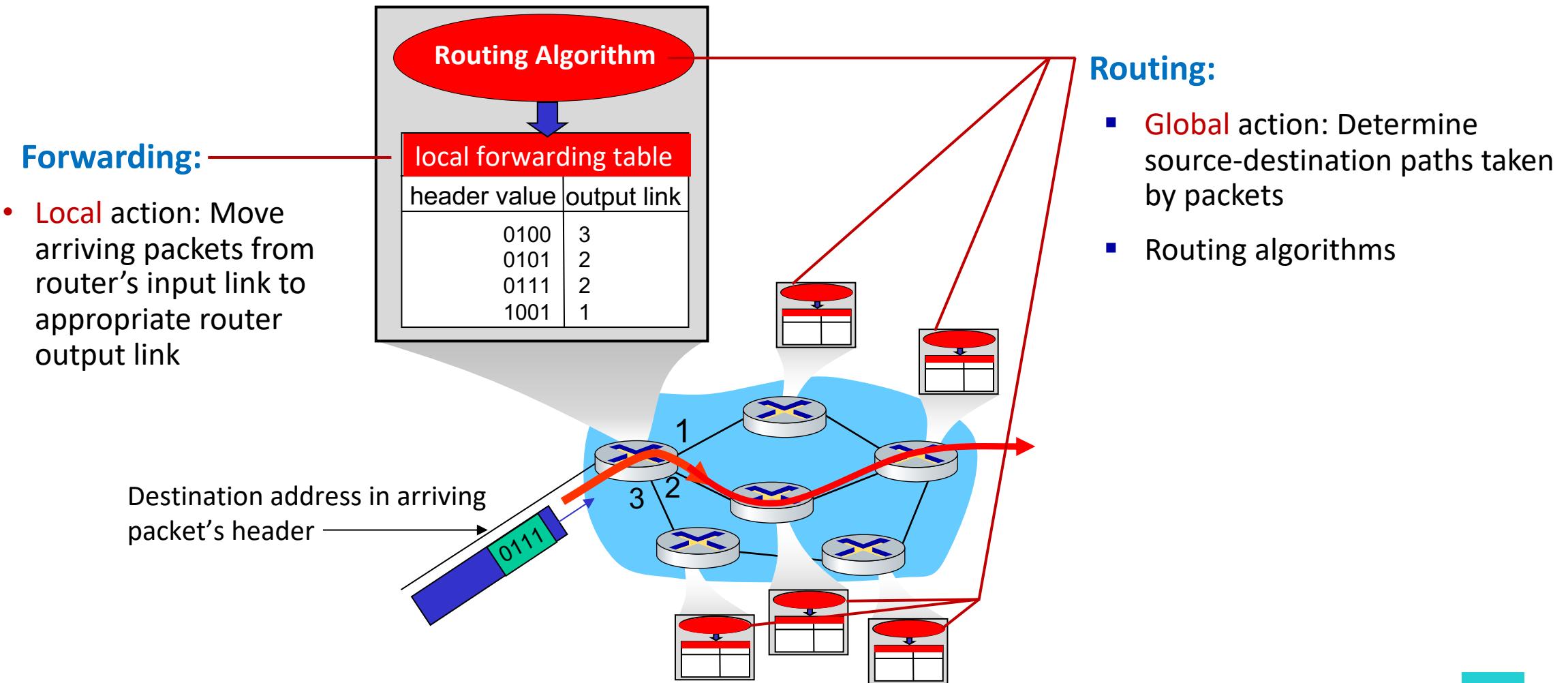
**Packet switching allows more users to use network!**

# Packet Switching

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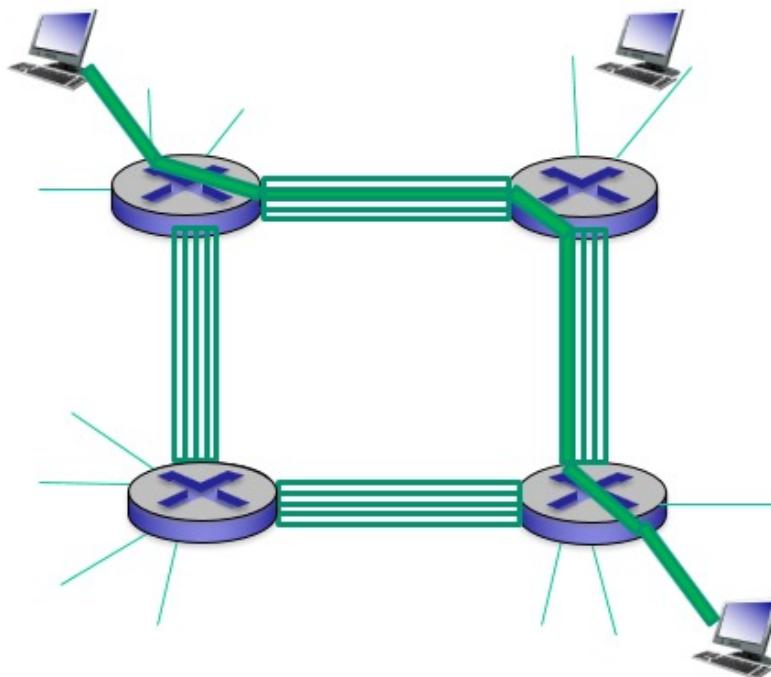
- Hosts break messages into packets
- Packets go **from one switch to the next** across links on path from source to destination
- Each packet transmitted at full link capacity
- Two key network-core functions
  - **Routing:** Determines source-destination route taken by packets
  - **Forwarding:** Moves packets from router's input to appropriate router output

# Packet Switching: Routing & Forwarding



# Packet Switching & Circuit Switching

## Circuit Switching



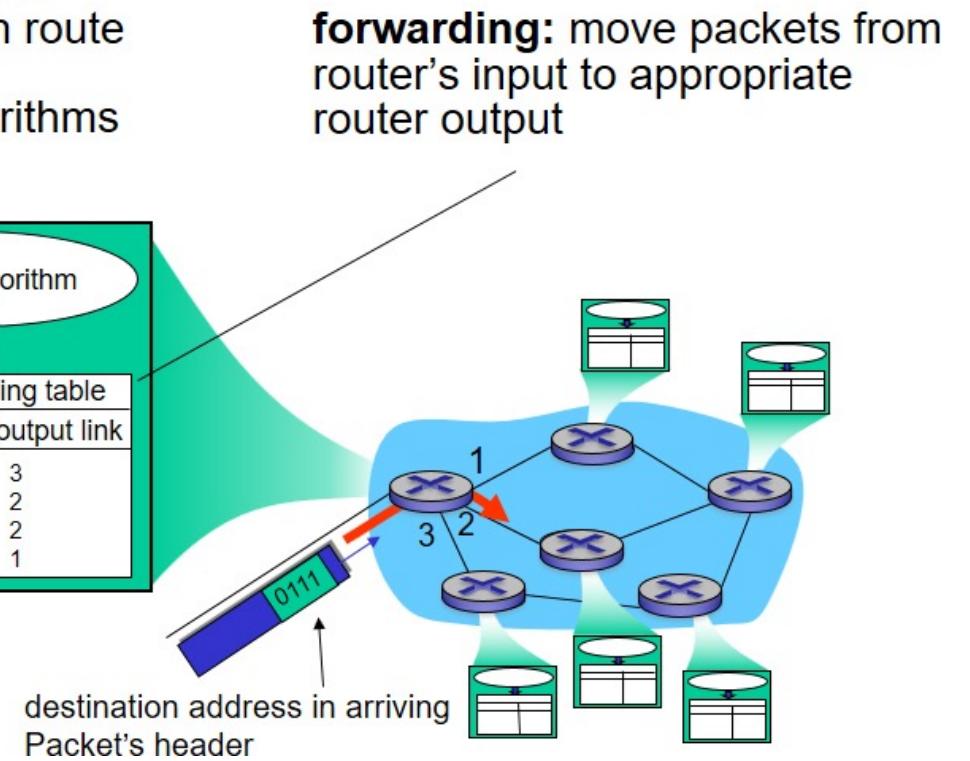
## Packet Switching

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

- routing algorithms

A diagram showing a local forwarding table. An arrow points from an oval labeled "routing algorithm" down to the table. The table has columns for "header value" and "output link". The data is as follows:

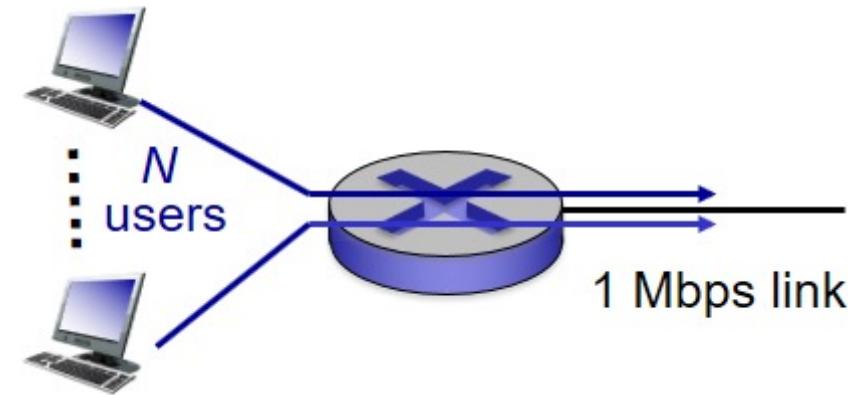
header value	output link
0100	3
0101	2
0111	2
1001	1



# Example

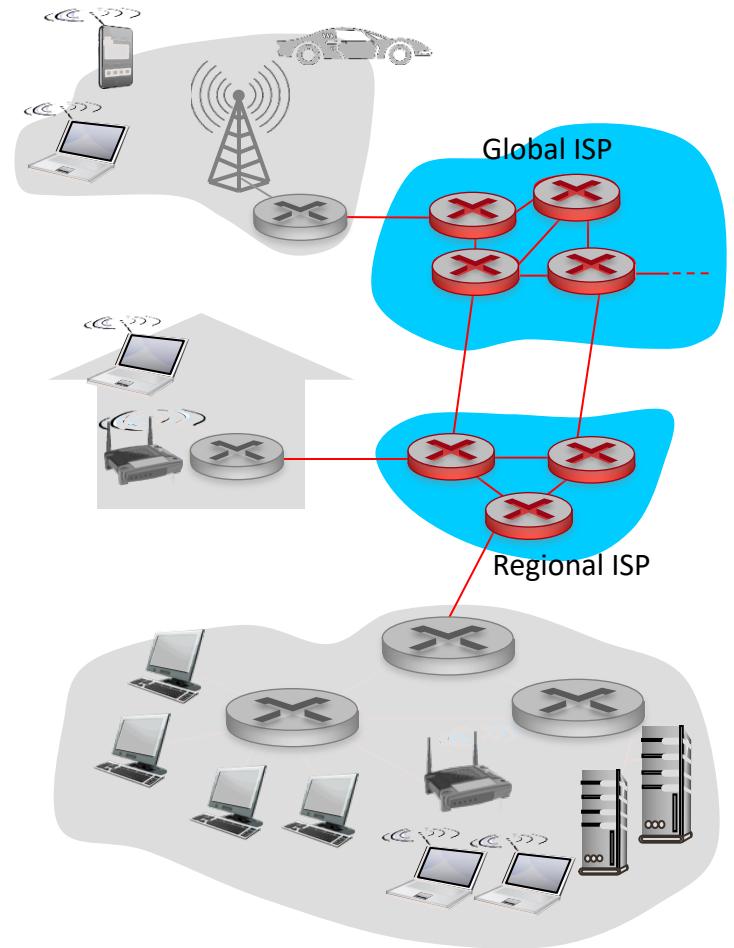
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- Each user **100 kbps** when active, and **active 10% of time**
- **Circuit-switching:** 10 users ( $1\text{Mbps} / 100\text{ Kbps} = 10$ )
- **Packet switching:**
  - Probability of single user active at any given time: 0.1
  - With 35 users probability that at any given time exactly 10 users are transmitting simultaneously:  
$$\binom{35}{10} \times 0.1^{10} \times (1 - 0.1)^{35-10}$$
  - Probability that when we have 35 users, more than 10 users are transmitting simultaneously?



# Network Core: Packet Switching

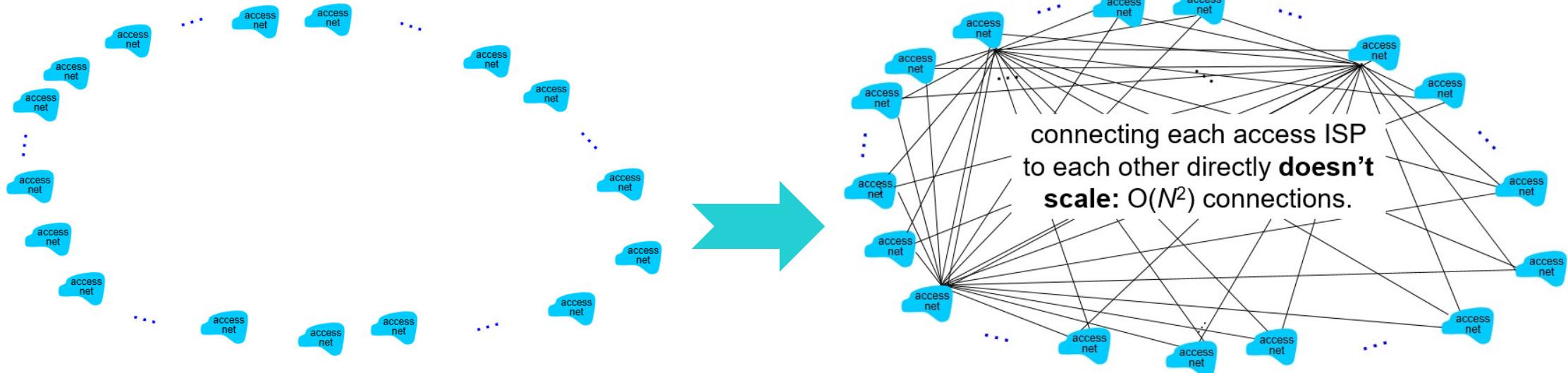
- Connect the access networks
  - Mesh of interconnected routers
  - Providing a path between source and destination through shared network resources
    - **Packet Switching**



# Internet Structure

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- How to connect ISPs together?



- Connect each access ISP to every other access ISP?

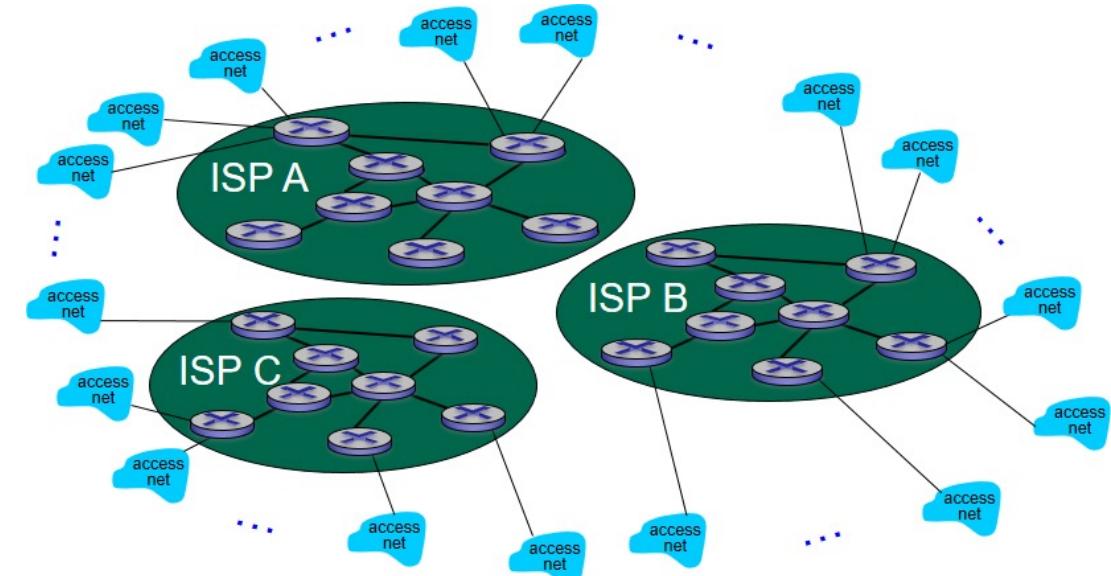
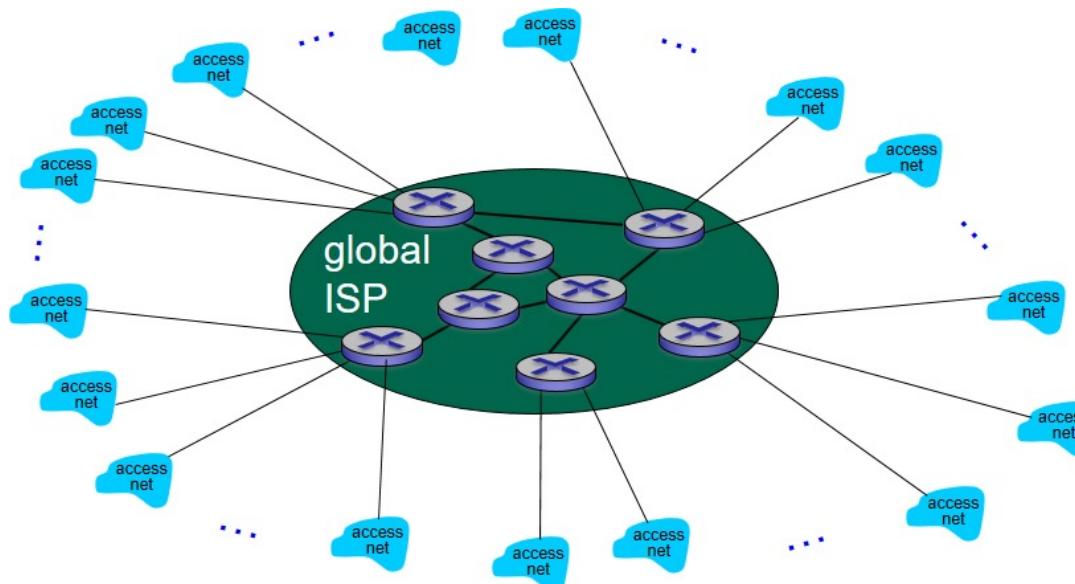
# Internet Structure

Connect each access ISP to one global transit ISP?

Customer & provider ISPs have economic agreement.

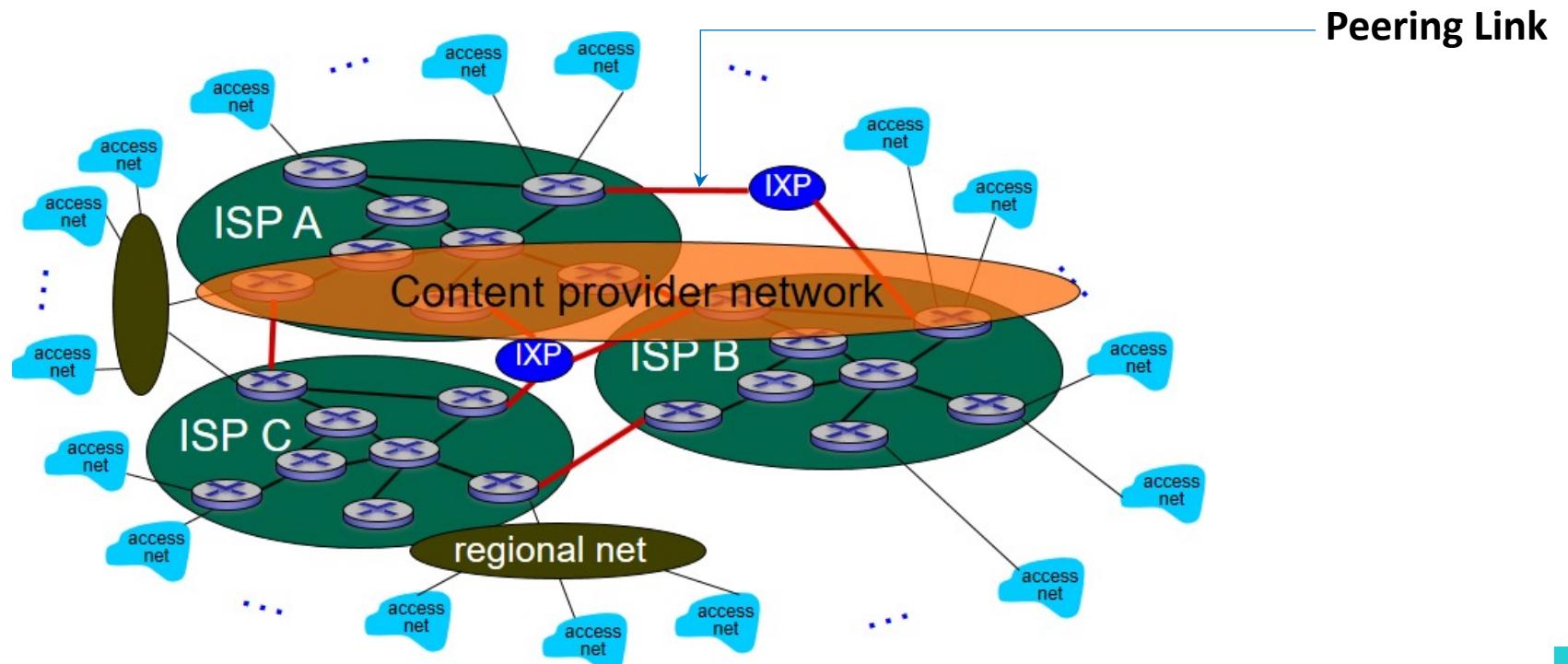


If one global ISP is a viable business,  
there will be competitors!



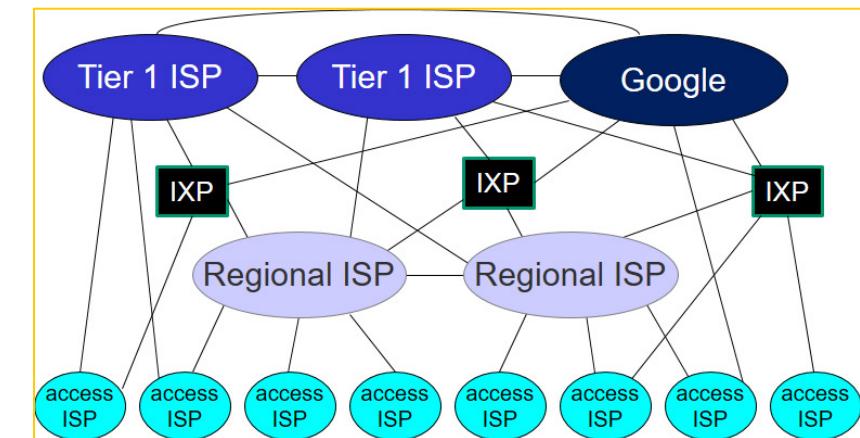
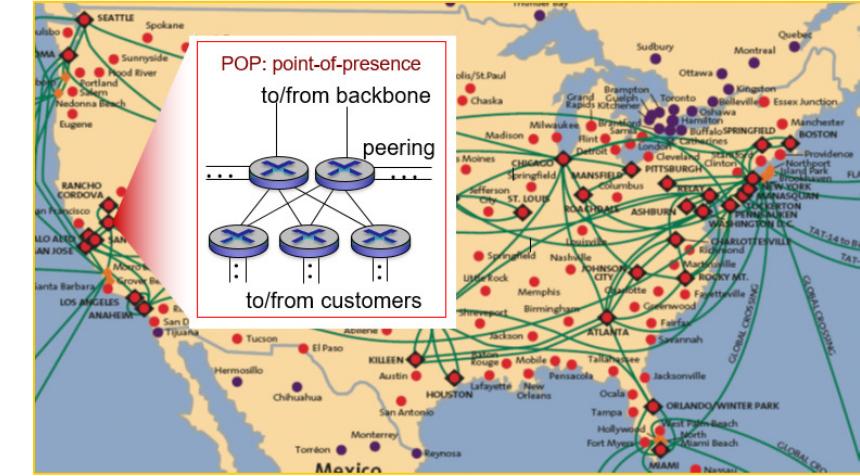
# Internet Structure

- **POP (Point of Presence)**: A provider ISP's location with a group of one or more routers where customer ISPs can connect into the provider ISP
- **Regional networks** may arise to connect access nets to ISPs
- **Content provider networks** (e.g., Google, Microsoft, Akamai) may run their own network, to bring services and content close to end users



# Internet Structure

- Center: Small number of well-connected large networks
  - **Tier-1 commercial ISPs**
    - Example: Sprint, AT&T
    - National and international coverage
  - **Content provider network**
    - Example: Google
    - Private network that connects its data centers to Internet often bypassing Tier-1 and regional ISPs



# Introduction: Network Performance



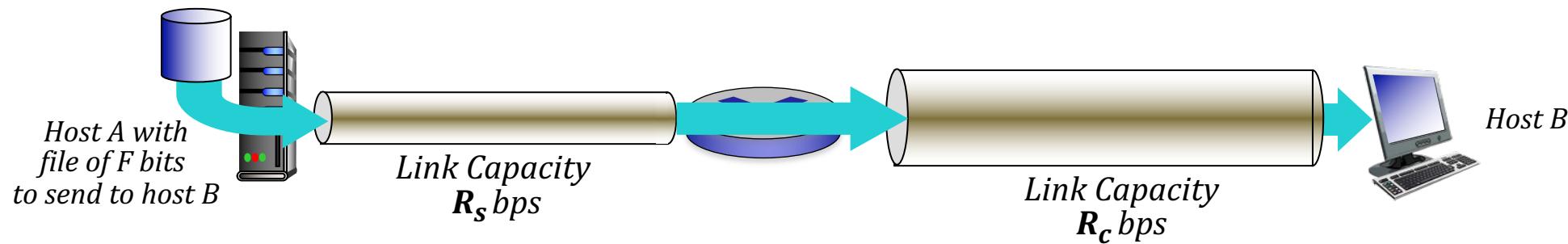
# Network Performance

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- Network Performance
  - Throughput (Bandwidth)
  - Delay (Latency)
  - Loss
  - Jitter
  - Delay x Bandwidth Product

# Throughput (Bandwidth)

- **Throughput:** Rate (bits/time unit) at which bits transferred between sender and receiver
  - **Instantaneous:** Rate at given point in time
  - **Average:** Rate over longer period of time

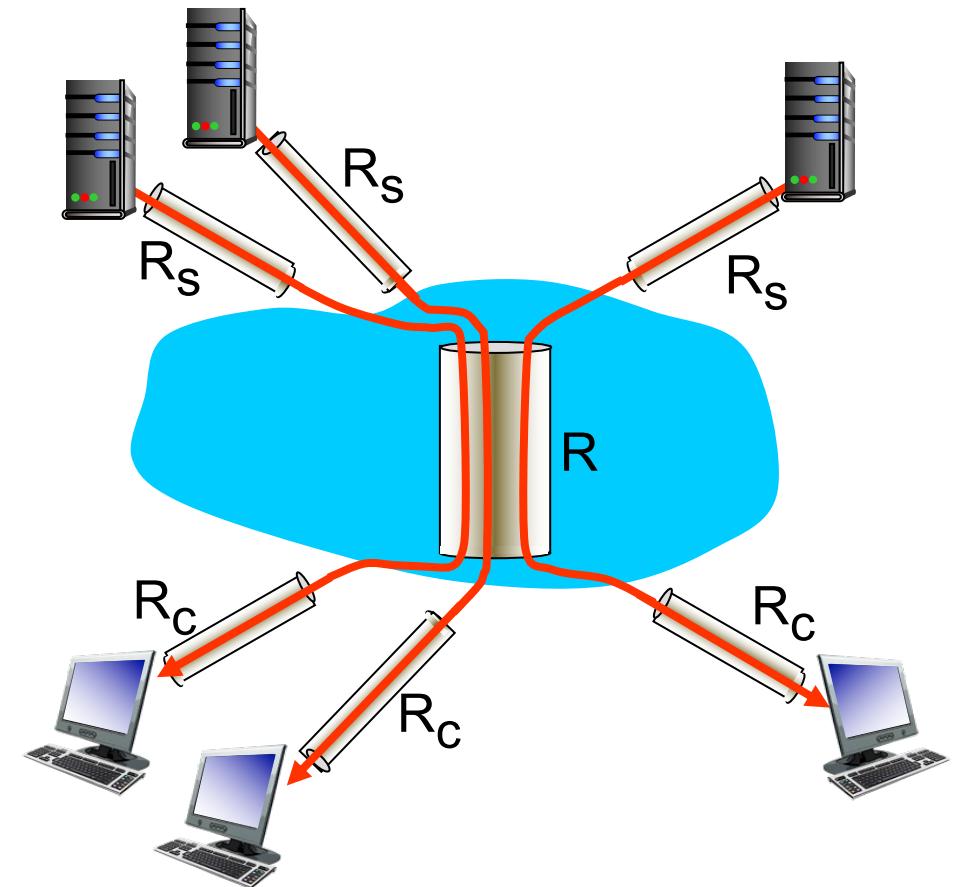


- **Bottleneck link:** Link on end-end path that constrains end-end throughput

# Throughput (Bandwidth)

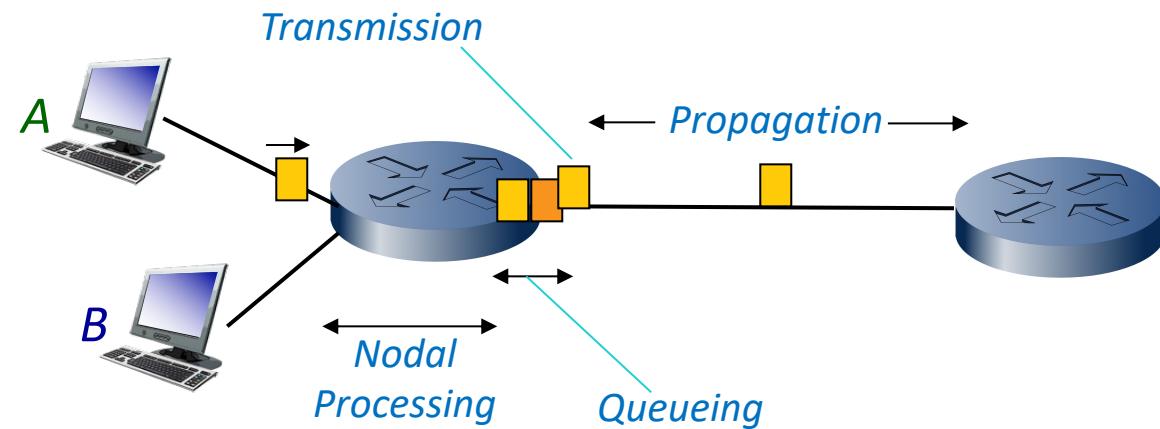
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- $N$  connections fairly share backbone bottleneck link  $R$  bps
- Per-connection end-end throughput:  $\min(R_c, R_s, R/N)$
- In practice  $R_c$  or  $R_s$  is often the bottleneck



# Delay (Latency)

- Packet Switching
  - Four sources of delay
    - Nodal Processing Delay
    - Queueing Delay
    - Transmission Delay
    - Propagation Delay

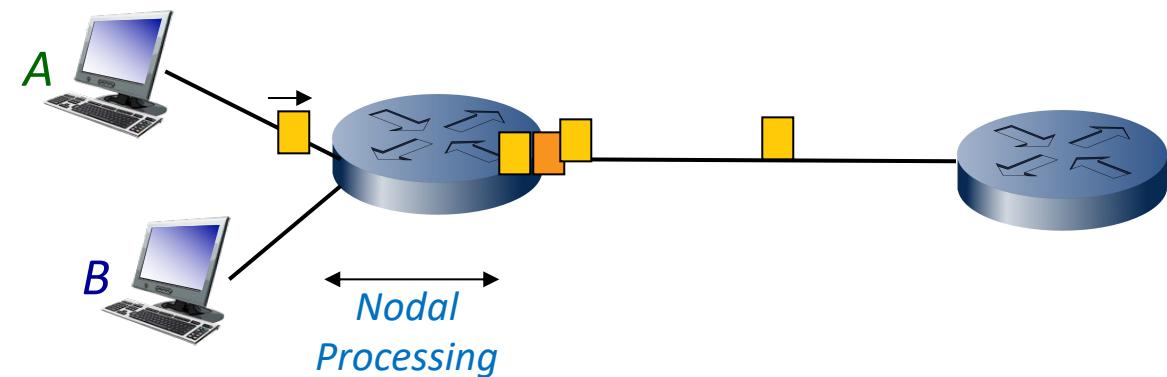


$$Delay = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

# Nodal Processing Delay

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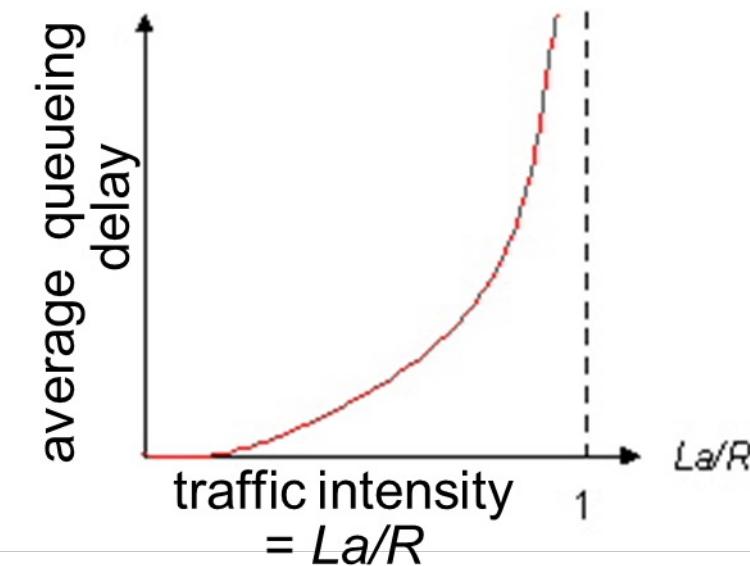
- Delays due to processing on the packet in a router ( $d_{proc}$ )
- Examples
  - Examining the header
  - Determining the outgoing link
  - Error checking



# Queueing Delay

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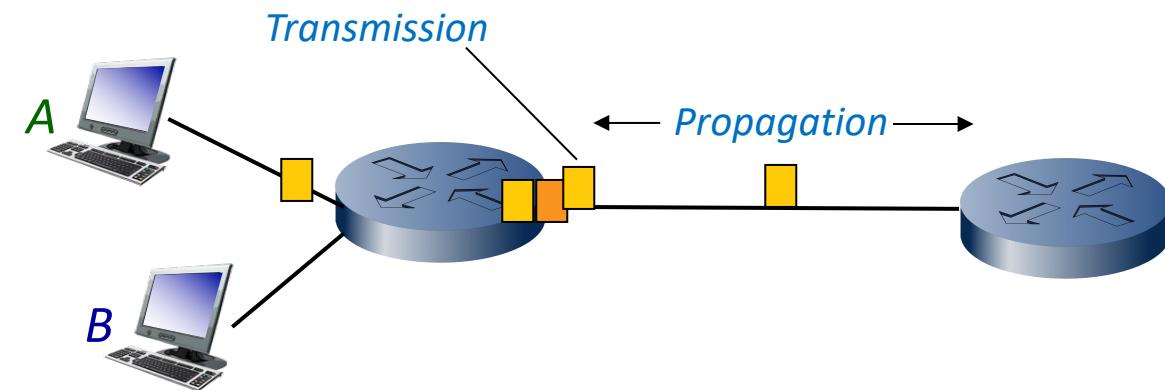
- **Traffic Intensity:  $La/R$** 
    - $R$ : Link bandwidth (bps)
    - $L$ : Packet length (bits)
    - $a$ : Average packet arrival rate
- $La/R \sim 0$  : Average Queueing Delay Small
- $La/R \rightarrow 1$  : Average Queueing Delay Large
- $La/R > 1$  : More work arriving than processed



# Transmission & Propagation Delays

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- Transmission Delay
  - Time required to transmit all packet bits on the link
  - $L/R$ 
    - L: Packet Length
    - R: Link Bandwidth



- Propagation Delay
  - Time required to propagate from the beginning to end of the link
  - $d/s$ 
    - d: Length of the link
    - s: Speed of propagation in the medium

# Delay

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- Packet Switching: Four sources of delay

- **Transmission Delay**

$d_{trans}$ : *transmission delay*:

- $L$ : Packet length (bits)
- $R$ : Link bandwidth (bps)
- $d_{trans} = L/R$

- **Propagation Delay**

$d_{prop}$ : *propagation delay*:

- $d$ : Length of physical link
- $s$ : Propagation speed in medium ( $\sim 2 \times 10^8$  m/sec)
- $d_{prop} = d/s$

- **Nodal Procession Delay**

$d_{proc}$ : *nodal processing*

- Check bit errors
- Determine output link
- Typically < msec

- **Queueing Delay**

$d_{queue}$ : *queuing delay*

- Time waiting at output link for transmission
- Depends on congestion level of router

# Jitter

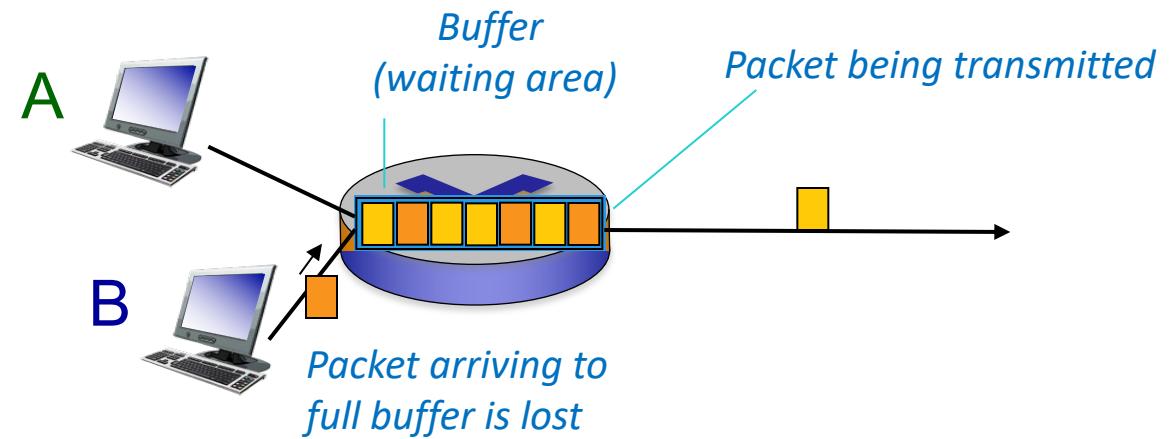
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- Packet delay variations
  - Packet delay difference between for different packets
- Important in real-time applications
- Mitigation by buffers at the receiver side

# Loss (Dropped Packets)

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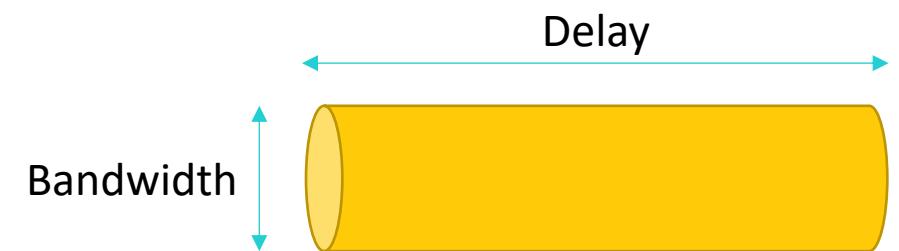
- Queue (aka buffer) preceding link in buffer has **finite** capacity
  - Packet arriving to full queue dropped (aka lost)
  - Lost packet may be retransmitted by previous node, by source end system, or not at all



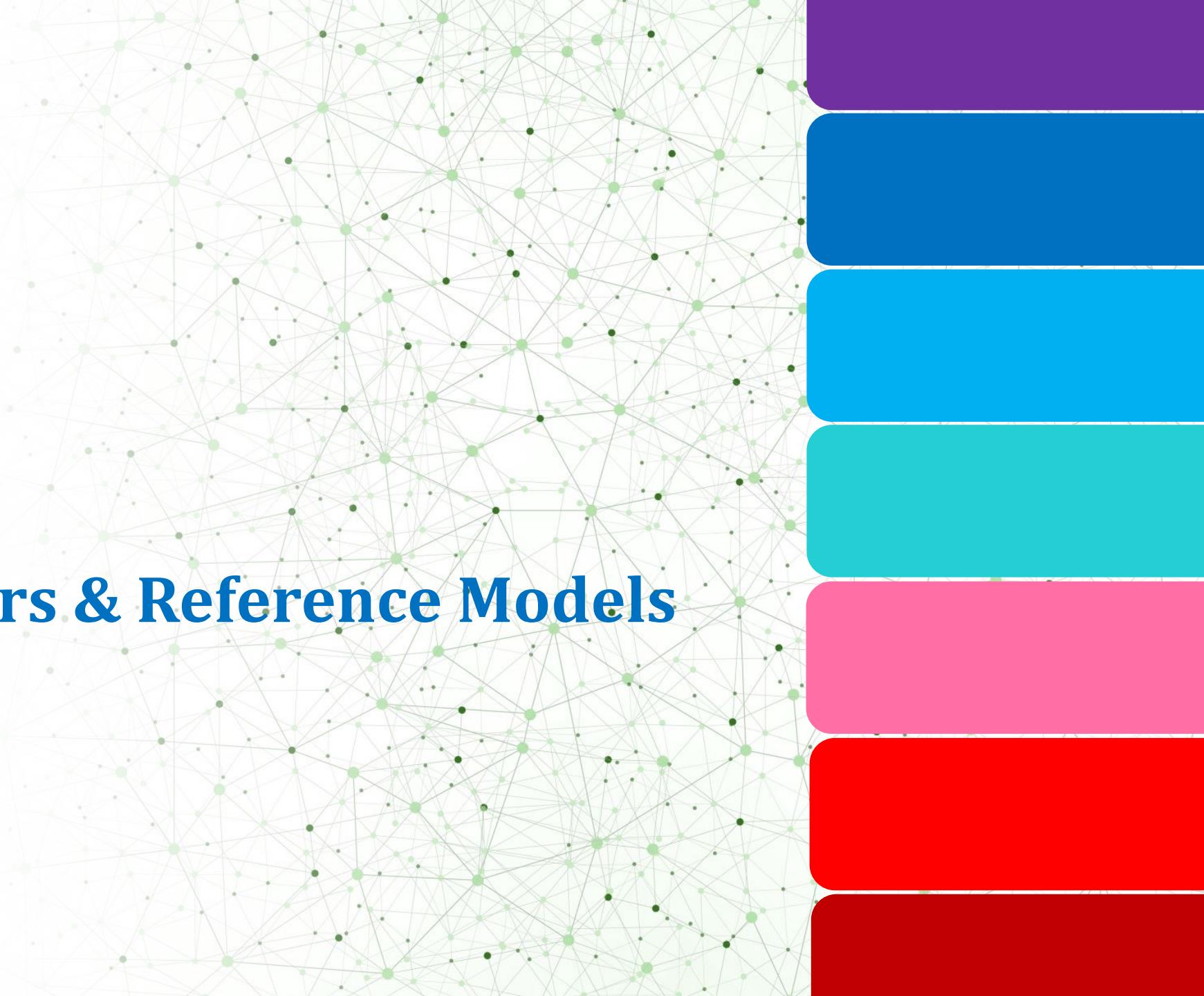
# Delay × Bandwidth Product

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- Delay × Throughput
  - If you consider network as a pipe, the delay bandwidth product provides the volume of the pipe

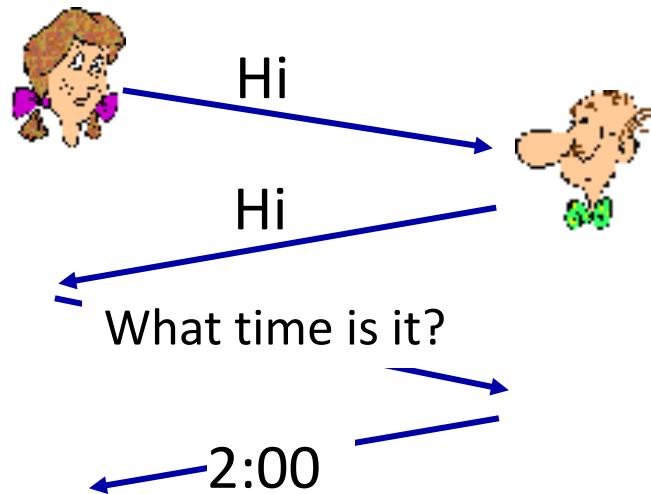


# **Introduction: Protocol Layers & Reference Models**



# Example: A Human Protocol

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# Protocols

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- Protocols
  - **Protocols** define **format, order of messages sent and received** among network entities, and **actions taken** on message transmission, receipt
  - Examples: TCP, IP, HTTP, Skype, 802.11
- Internet Standards
  - RFCs: Request For Comments
  - IETF: Internet Engineering Task Force

# Example RFC

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<https://tools.ietf.org/html/rfc7235>

Internet Engineering Task Force (IETF)  
Request for Comments: 7235  
Obsoletes: [2616](#)  
Updates: [2617](#)  
Category: Standards Track  
ISSN: 2070-1721

R. Fielding, Ed.  
Adobe  
J. Reschke, Ed.  
greenbytes  
June 2014

## Hypertext Transfer Protocol (HTTP/1.1): Authentication

### Abstract

The Hypertext Transfer Protocol (HTTP) is a stateless application-level protocol for distributed, collaborative, hypermedia information systems. This document defines the HTTP Authentication framework.

### Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in [Section 2 of RFC 5741](#).

# Reference Model

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Dealing with complex systems

- Explicit structure allows identification and relationship of pieces
  - Layered **reference model** for discussion
- Modularization eases maintenance, updating of system
  - Change of implementation of layer's service transparent to rest of system

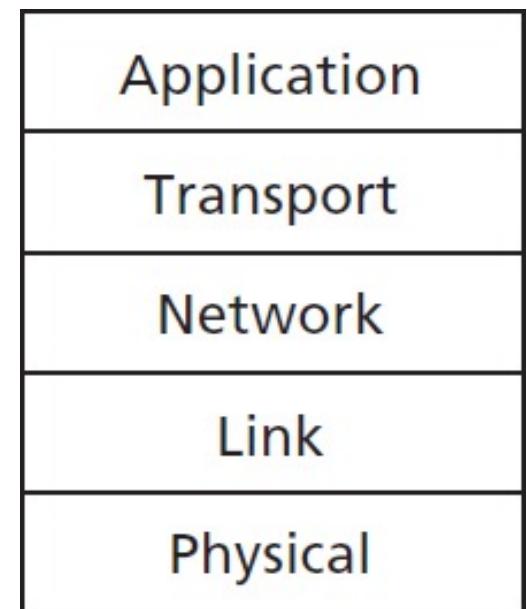
**Layers:** Each layer implements a service

- Via its own internal-layer actions
  - Relying on services provided by layer below
- 
- **Could layering be harmful?**

# Internet Protocol Stack

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- **Application:** Supporting network applications
  - FTP, SMTP, HTTP
- **Transport:** Process-process data transfer
  - TCP, UDP
- **Network:** Routing of datagrams from source to destination
  - IP, routing protocols
- **Link:** Data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- **Physical:** bits “on the wire”



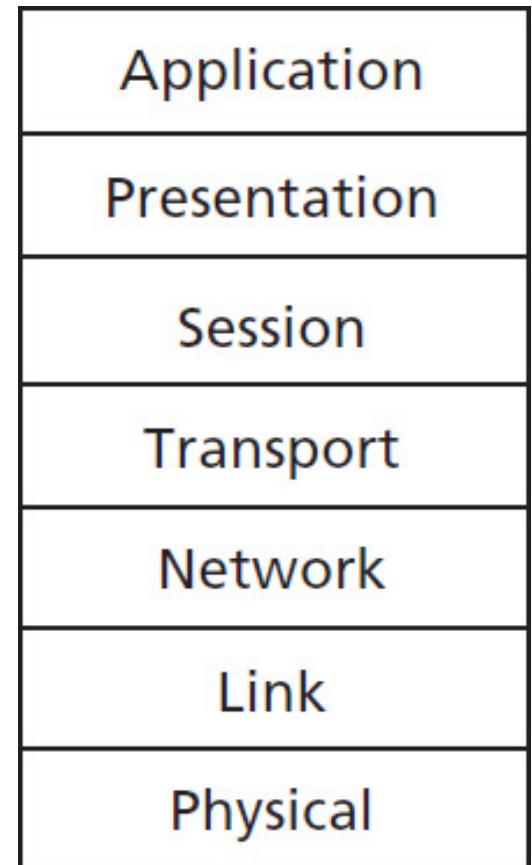
# OSI/ISO Reference Model

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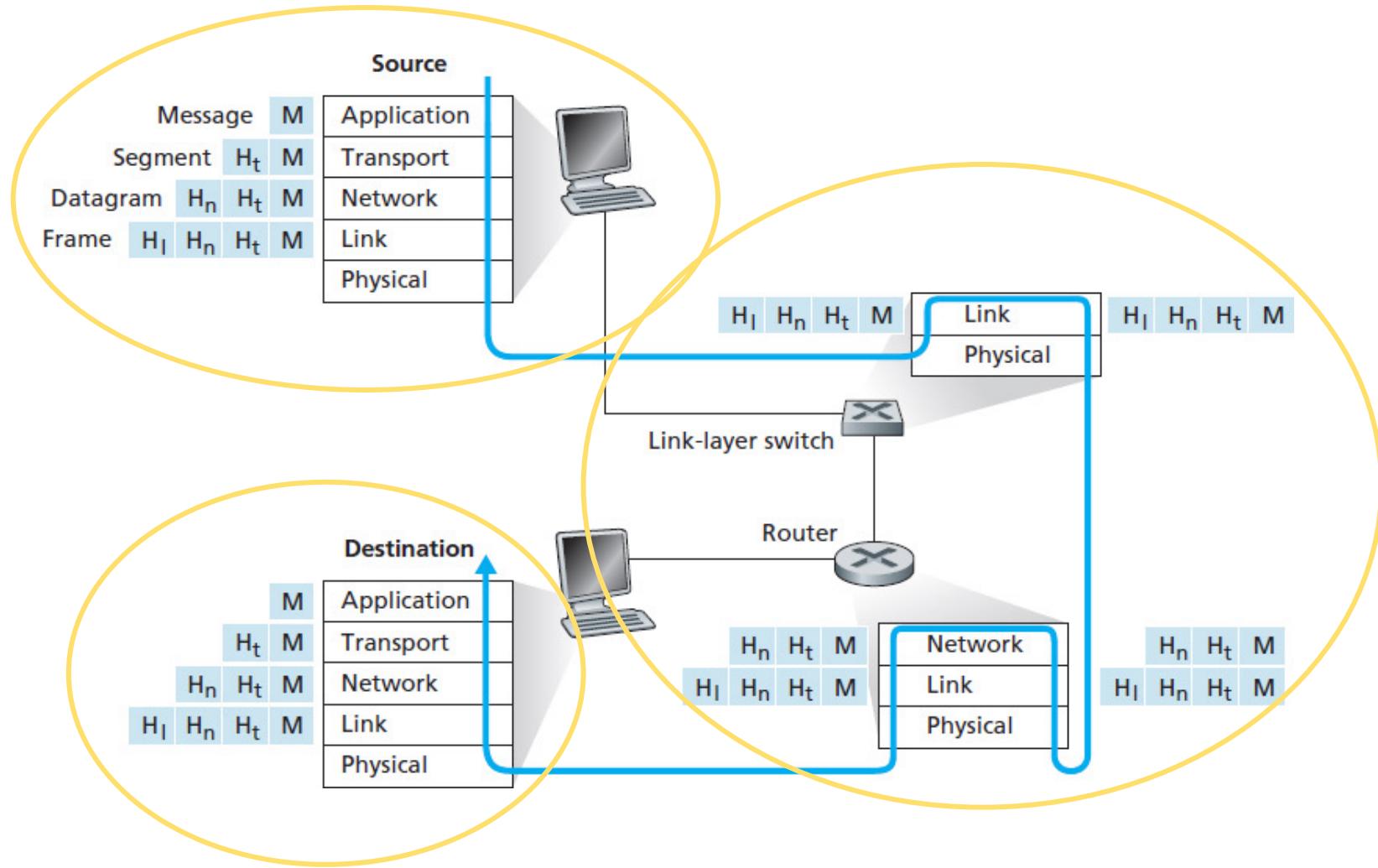
## Additional layers to Internet Protocol Stack

- **Presentation:** Allow applications to interpret meaning of data
  - Encryption
  - Compression
  - Machine-specific conventions
- **Session:** Synchronization, checkpointing, recovery of data exchange

Internet stack missing these layers. These services, **if needed**, must be implemented in application.

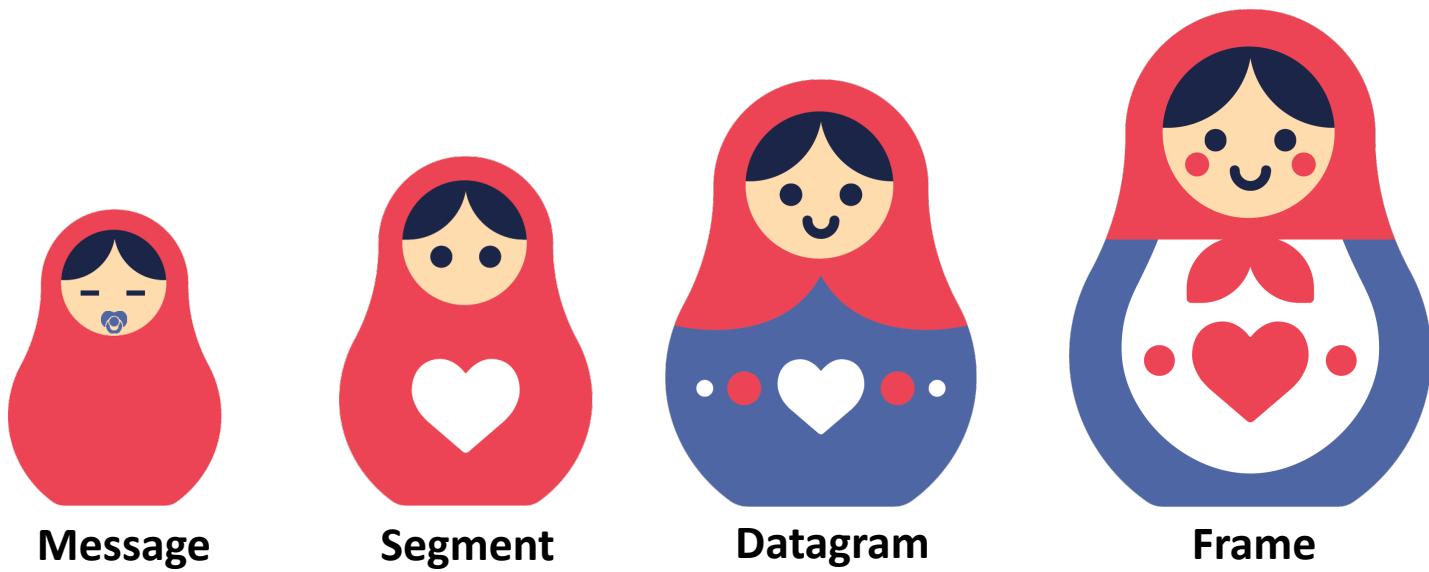


# Encapsulation



# Encapsulation

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**Message**

**Segment**

**Datagram**

**Frame**

# Introduction: Network Security



# Network Security

---

- Internet not originally designed with (much) security in mind
  - Original vision: A group of mutually trusting users attached to a transparent network
- Important
  - How networks could be attacked
  - How we can defend networks against attacks
  - How to design architectures that are immune to attacks

# Networks Under Attack

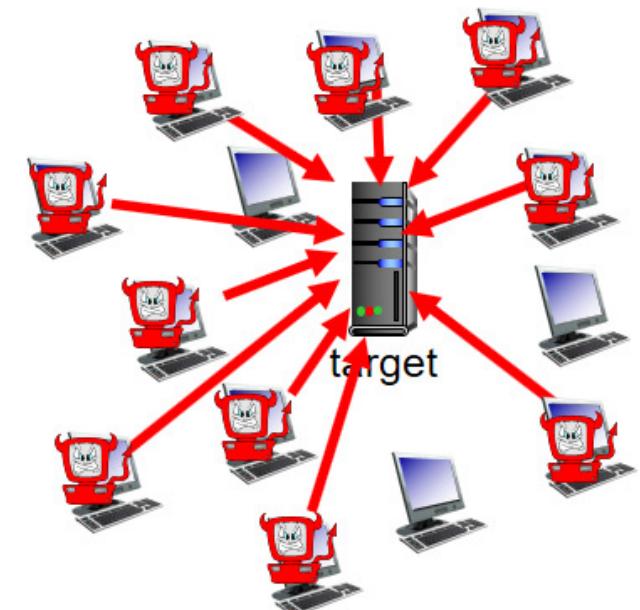
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- Malware for hosts spread through the network
  - Virus: Self-replicating infection by receiving/executing object (e.g. e-mail attachment)
  - Worm: Self-replicating infection by passively receiving object that gets itself executed
- Spyware: Can record keystrokes, web sites visited, upload info to collection site
- Spoofing (IP Spoofing)

# Denial of Service

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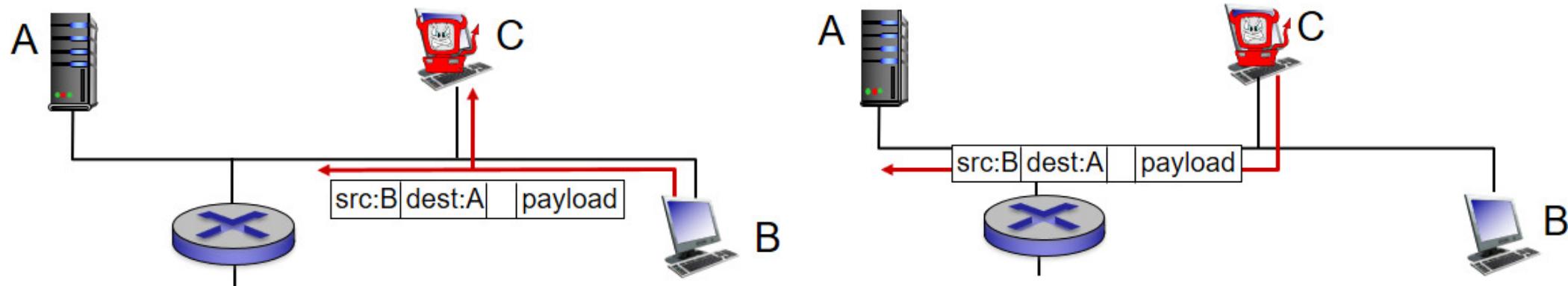
- **Denial of Service (DoS):** attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic
  - Select target
  - Break into hosts around the network (see botnet)
  - Send packets to target from compromised hosts



# Packet Sniffing

## Packet Sniffing:

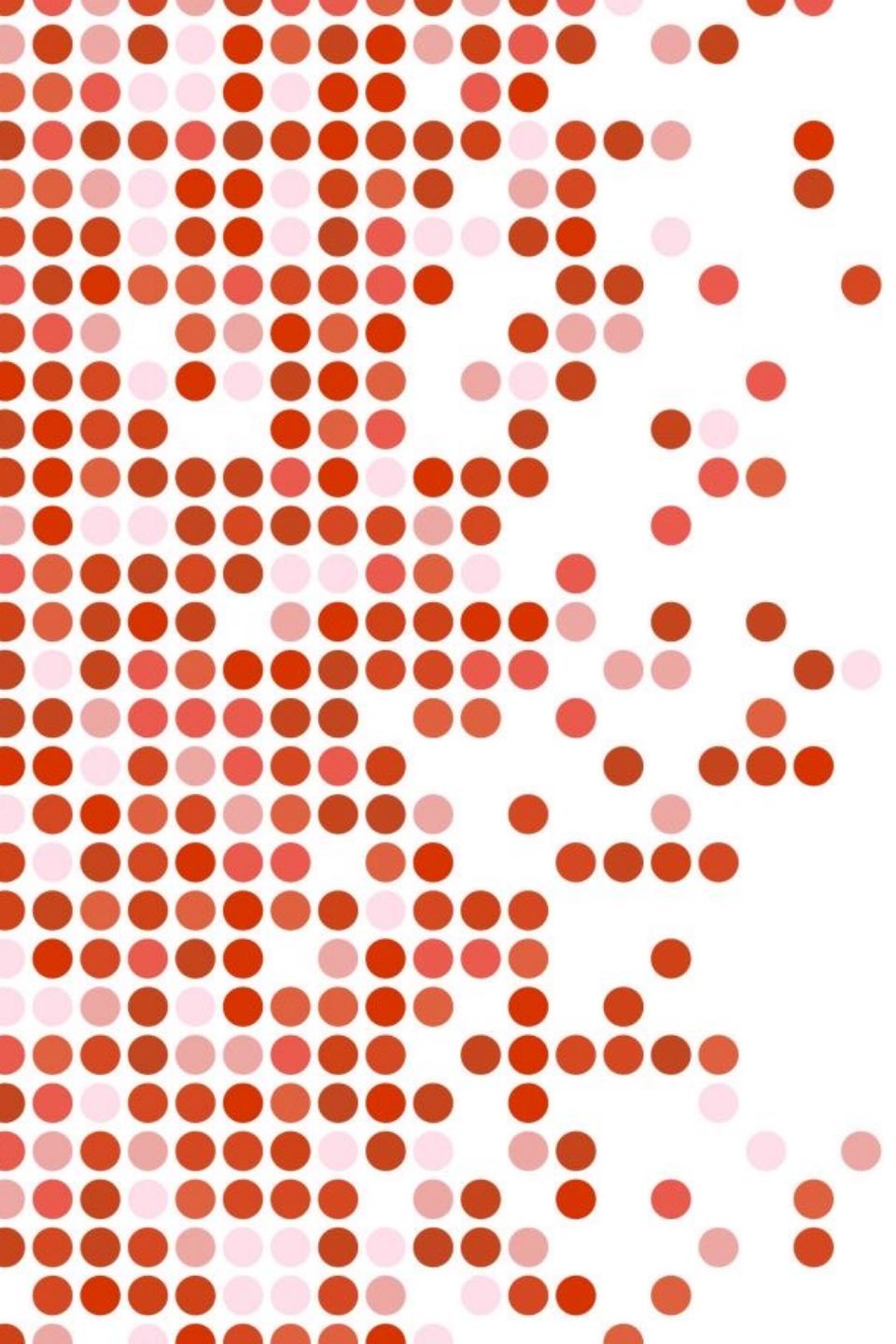
- Broadcast media (shared Ethernet, wireless)
- Promiscuous network interface reads/records all packets passing by (e.g. including passwords)



# Network Security

---

- Internet not originally designed with (much) security in mind
  - Original vision: A group of mutually trusting users attached to a transparent network
- Important
  - **How networks could be attacked**



# Introduction: Brief History of Networking



# History of Computer Networks

Kleinrock, Queuing Theory  
(Effectiveness of Packet Switching)

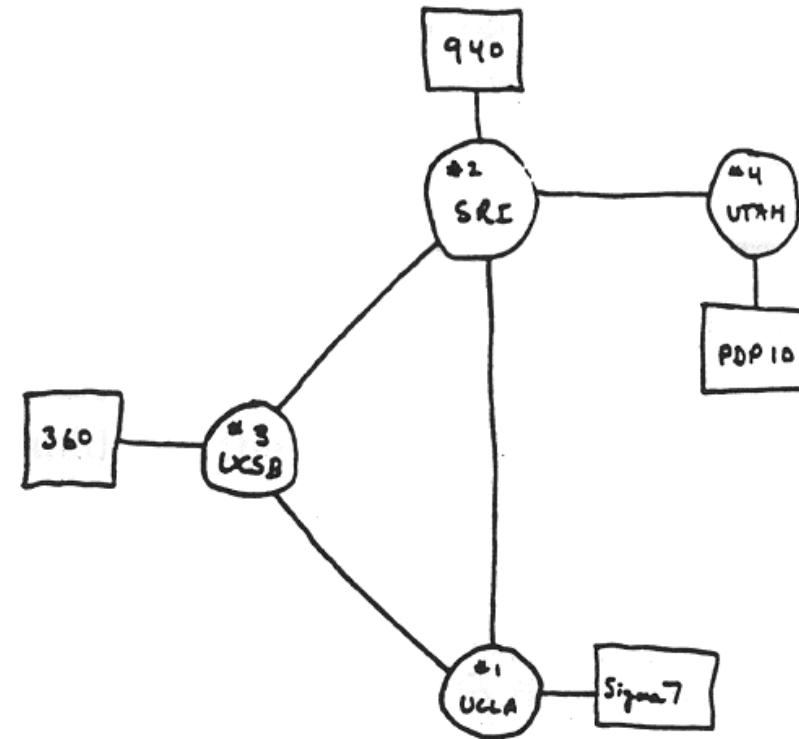
Baran (Packet Switching for Secure Voice in Military Nets)  
Davies & Scantlebury

ARPANet Conceived  
First ARPANet node  
ARPANet public demo  
NCP  
Email

1961                    1970

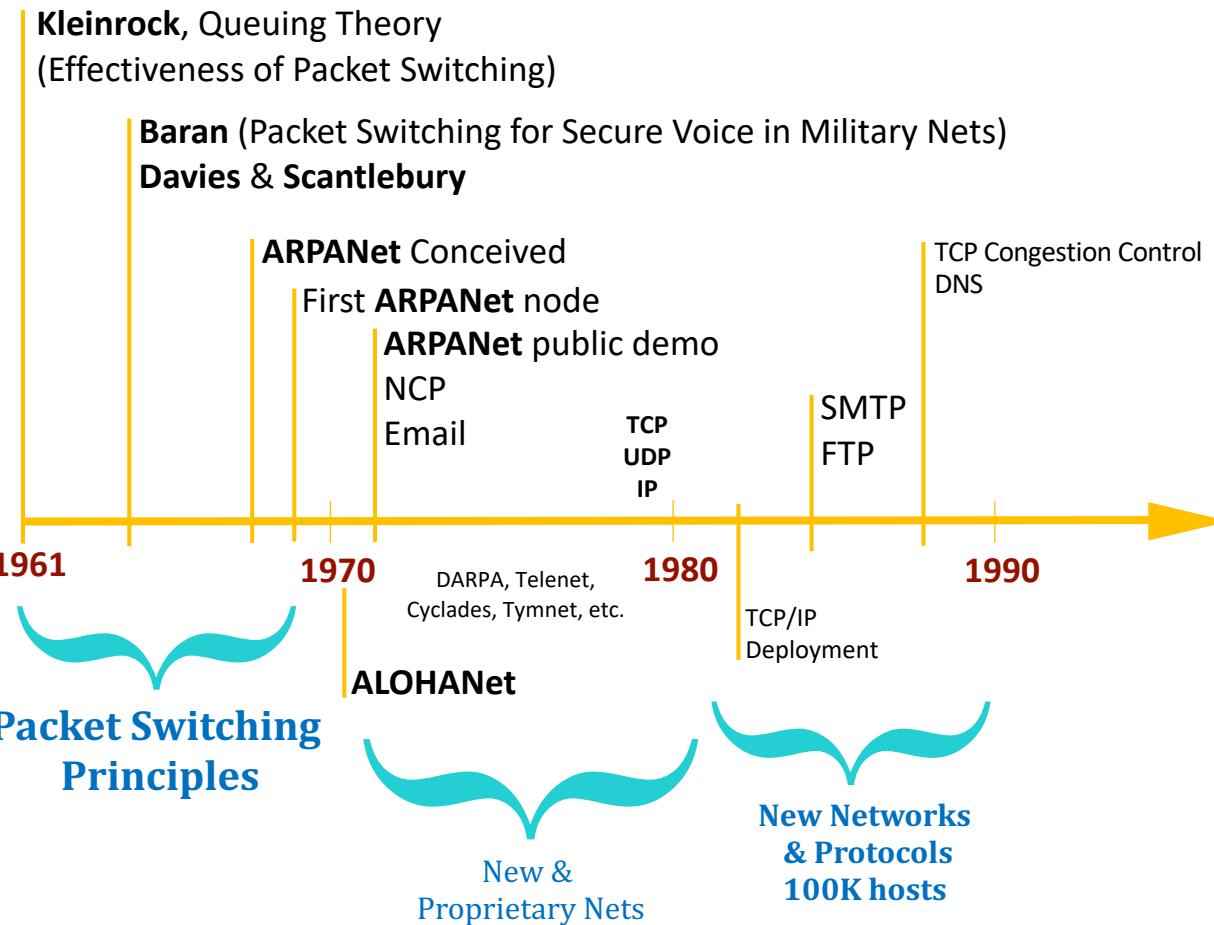


Packet Switching  
Principles

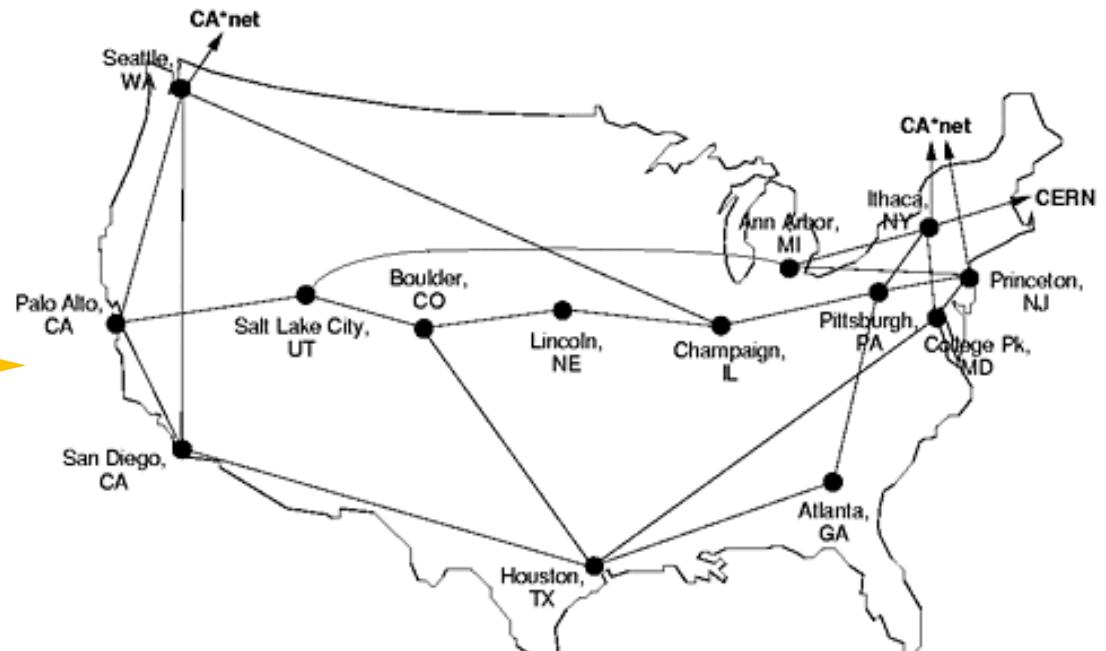


THE ARPA NETWORK

# History of Computer Networks

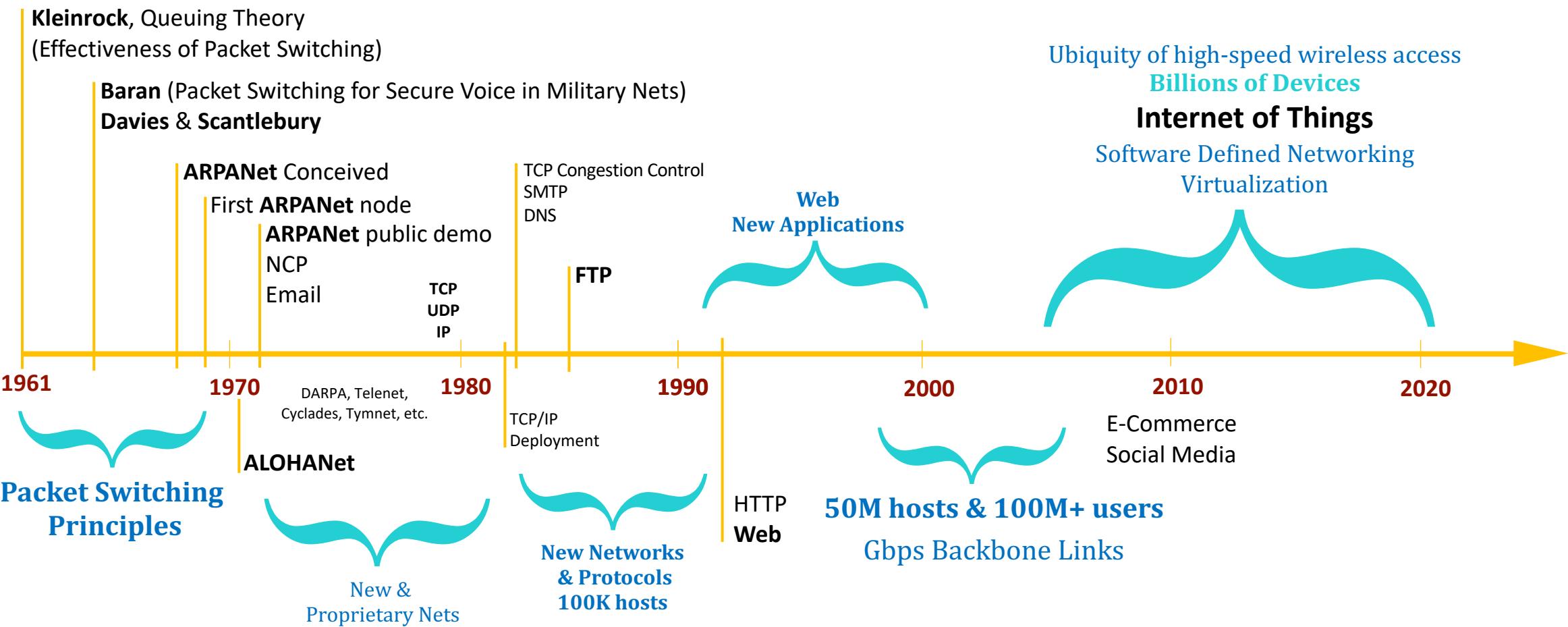


NSFNET T1 Network 1991



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# History of Computer Networks

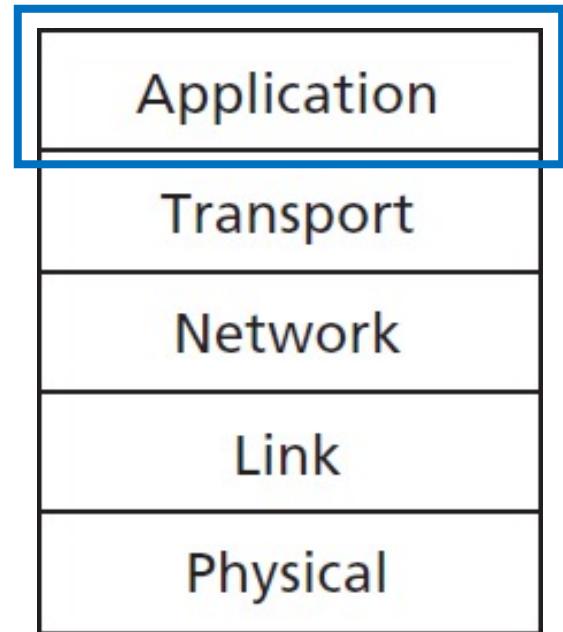


<https://www.internetsociety.org/internet/history-internet/brief-history-internet/>

# Summary

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- The Internet
- Basics
  - Network Edge
  - Network Core
  - Network Performance
- Protocol Layers and Reference Models
- Network Security: Networks Under Attack
- Brief History of Networking



# Acknowledgements

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- The following materials have been used in preparation of this presentation:

**[1] Textbook and (edited) Slides: Computer Networking: A Top-Down Approach**

James Kurose, Keith Ross

7<sup>th</sup> and 8<sup>th</sup> Edition, Pearson

[http://gaia.cs.umass.edu/kurose\\_ross/](http://gaia.cs.umass.edu/kurose_ross/)

**[2] Reference: Computer Networks: A Systems Approach**

<https://www.systemsapproach.org/book.html>

- Recommended Additional Resources:

**[1] Interactive Exercises (Chapter One)**

[http://gaia.cs.umass.edu/kurose\\_ross/interactive/](http://gaia.cs.umass.edu/kurose_ross/interactive/)

**[2] History of Networking (Podcast)**

<https://rule11.tech/history-of-networking/>