Introduction

Introduction

- 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

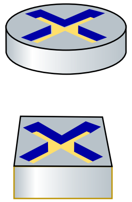
Introduction:
The Internet

The Internet

- Nuts and Bolts
  - **Hosts**
    - **End systems** running network applications

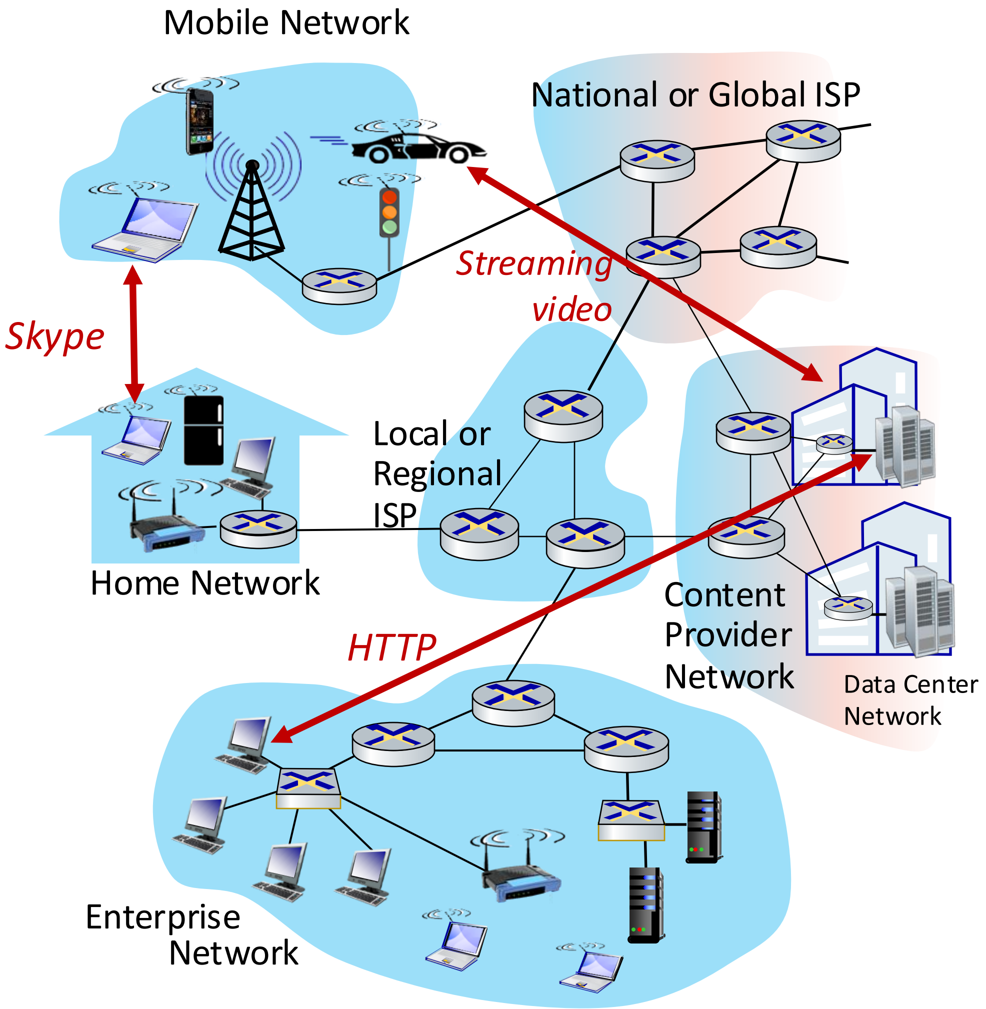
  - Communication Links
    - Fiber, Copper, Radio, Satellite

  - Switches and Routers
    - Find other switches and routers along the path to destination and forward data



The Internet

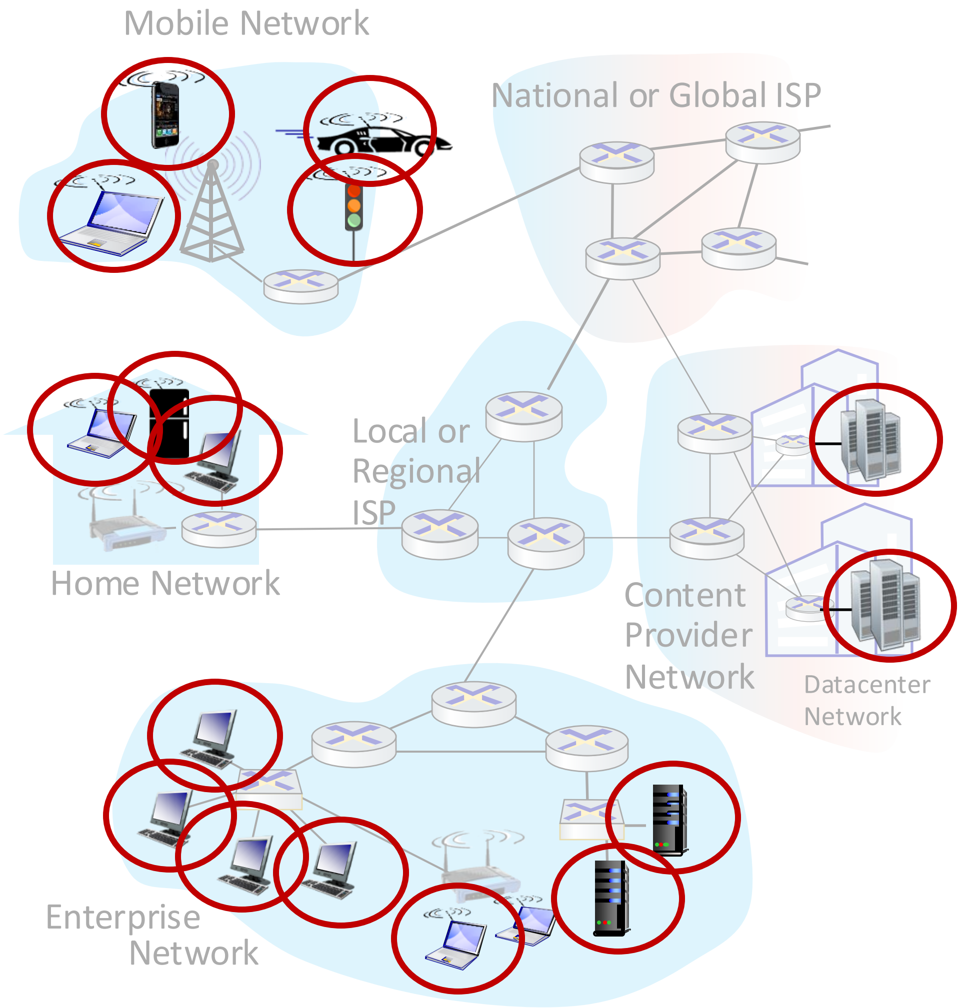
- Network of networks: Interconnected ISPs
  - Infrastructure providing **service** to applications
  - Infrastructure providing **programming interfaces (Socket Interface)** to applications



Introduction:
Network Edge

Network Edge

- Network Edge: Includes end systems
- Access Network



Network Edge

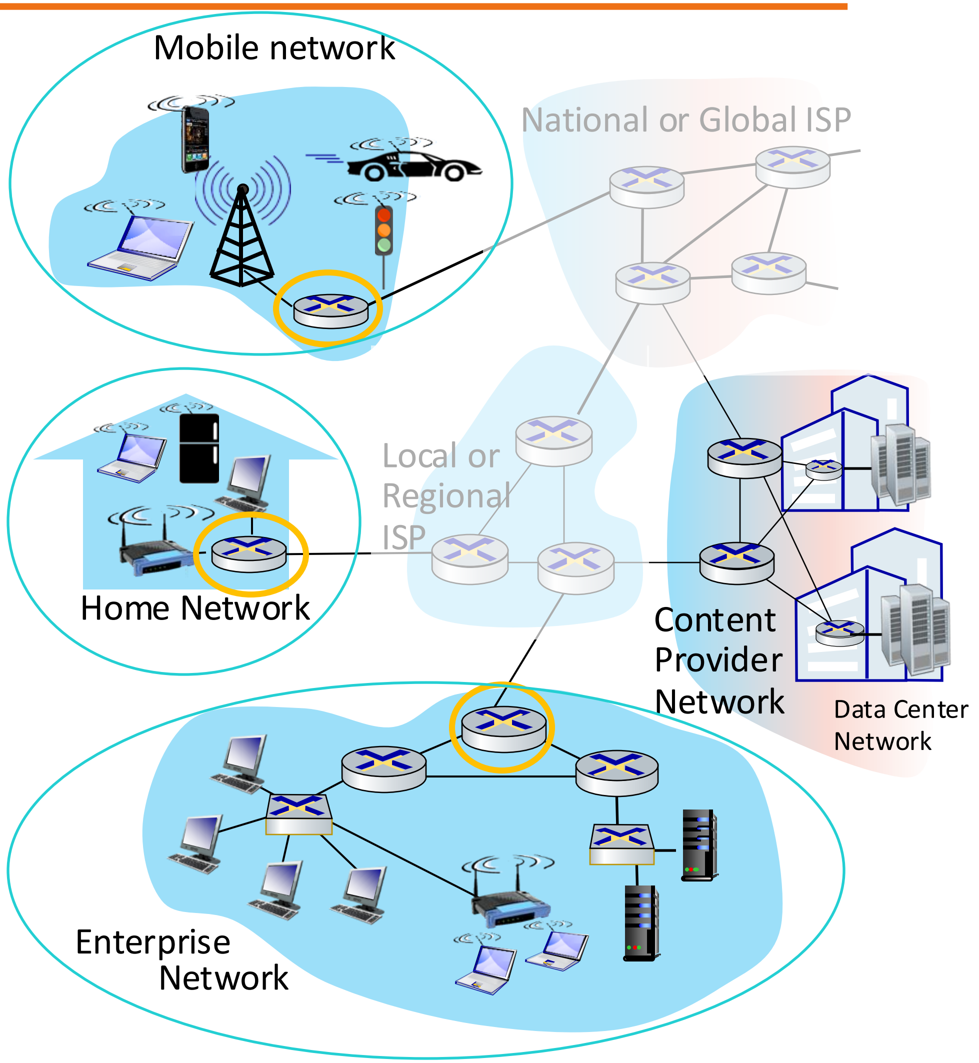
- Network Edge: Includes end systems

- 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

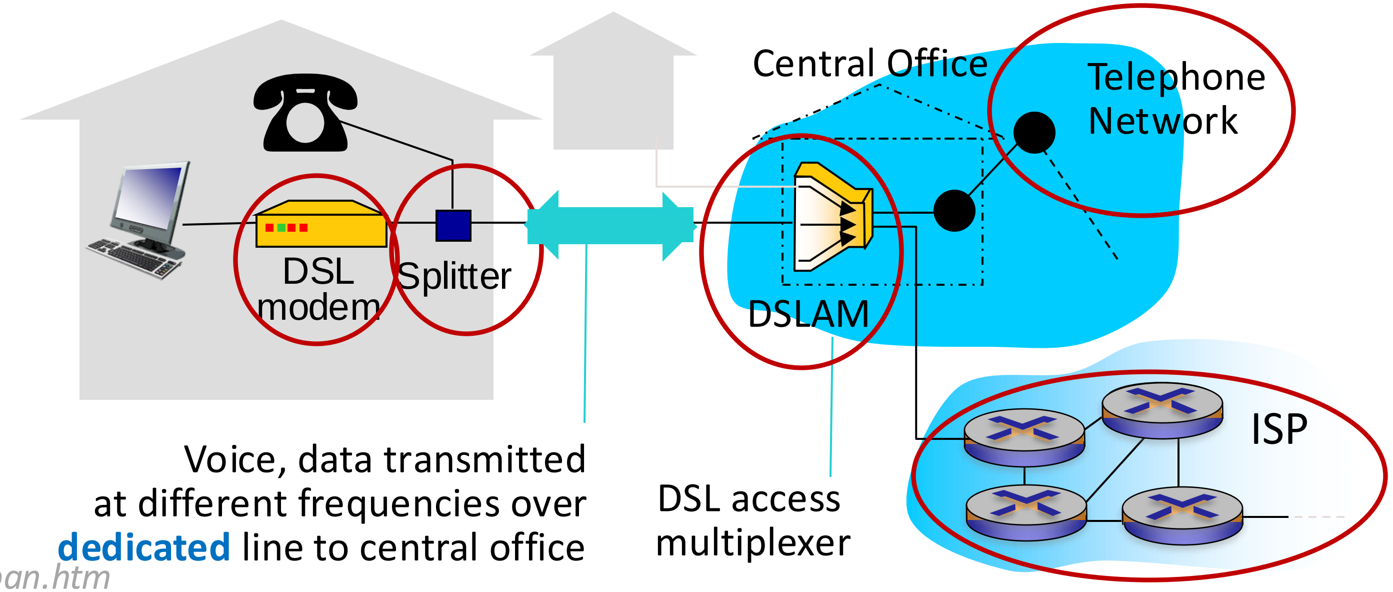
    - Enterprise Access
      - WiFi
      - Ethernet

    - 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



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

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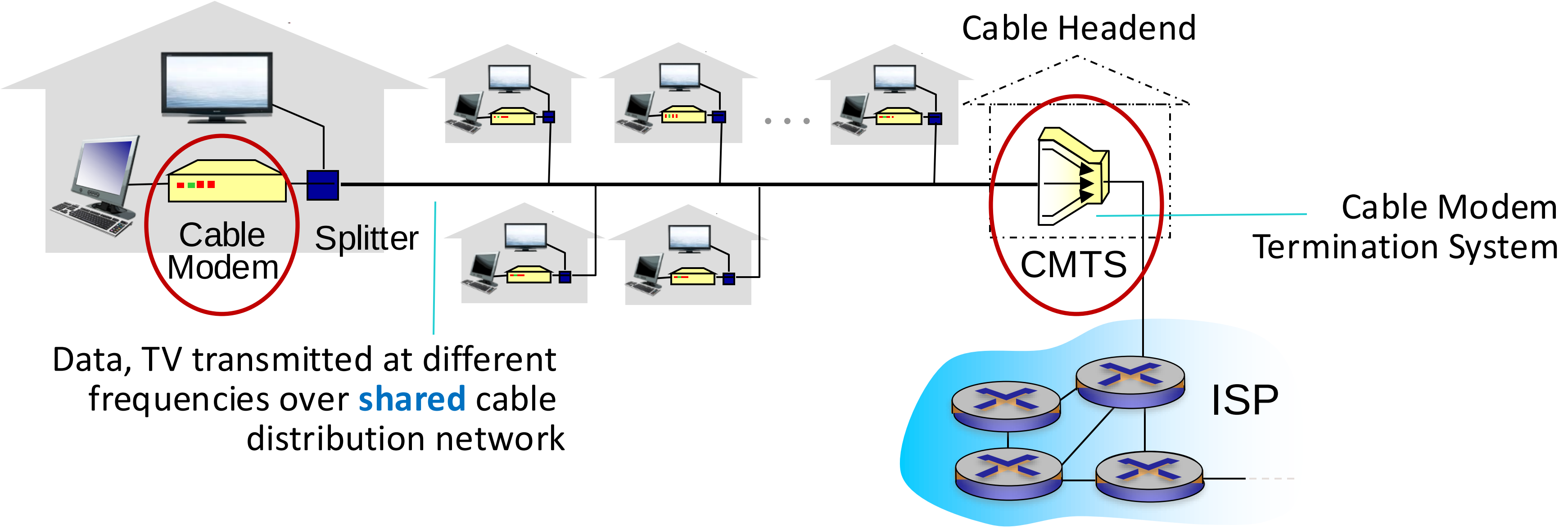
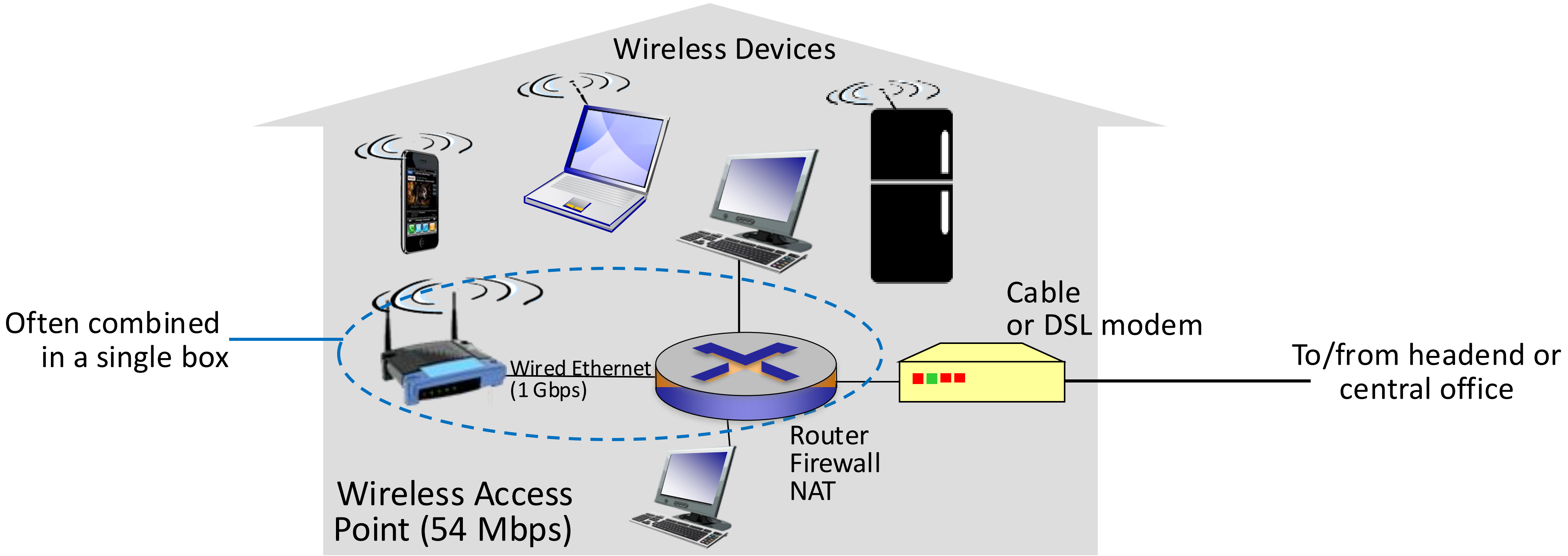
Access Networks: Cable Network

- **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



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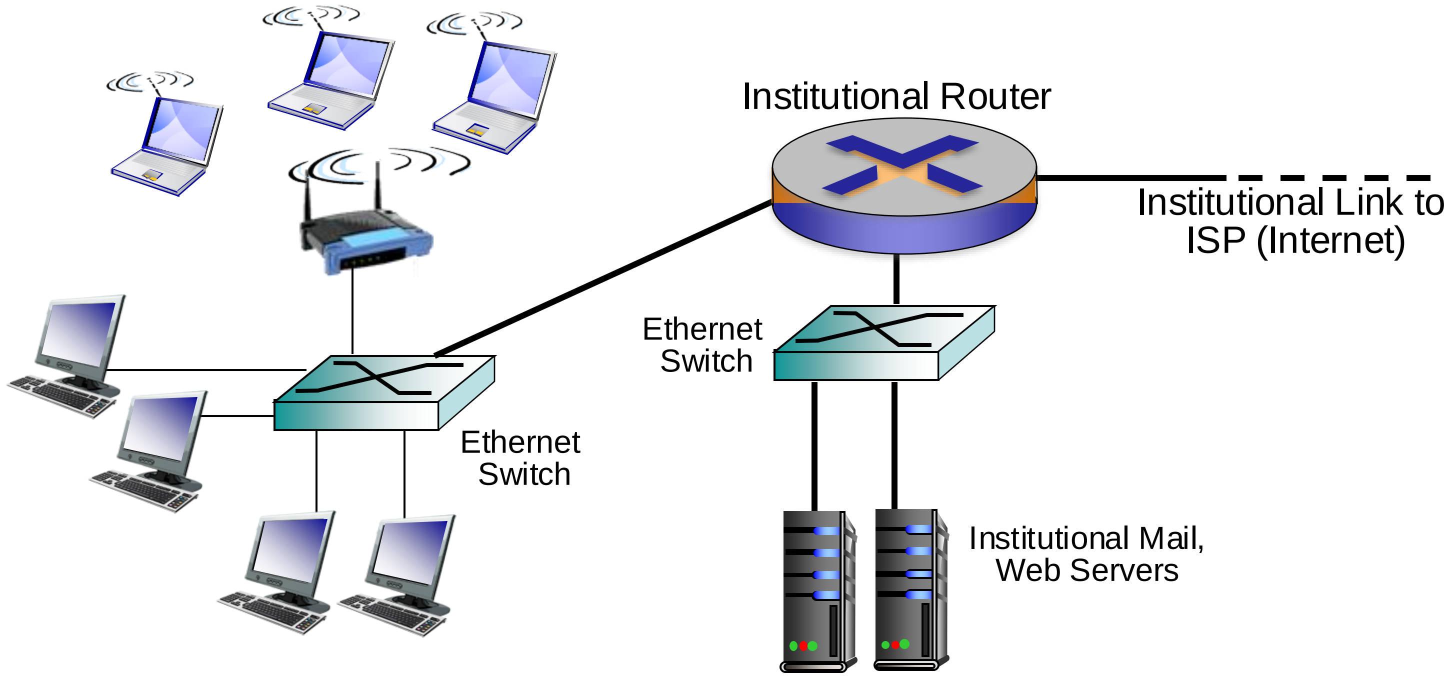
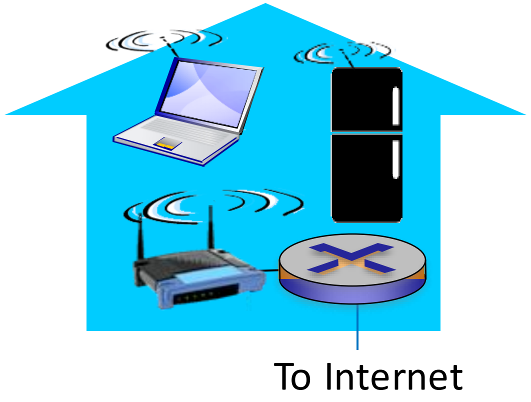
Access Networks: Enterprise Access

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



Wireless Access Networks

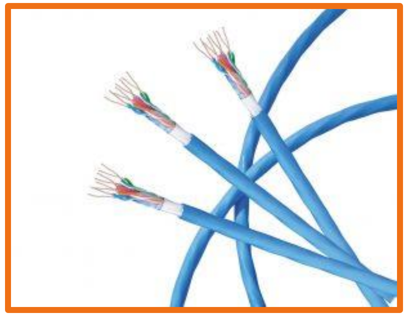
- Wireless Local Access Networks (LANs)
  - Shared **wireless** access network connects end system to router (through access point)
  - Within building
  - 802.11b/g/n/ac/ax (WiFi)



- Wide-Area Wireless Access (WANs)
  - Provided by telco (cellular) operator
  - 3G, 4G/LTE, 5G

Access Media

- 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



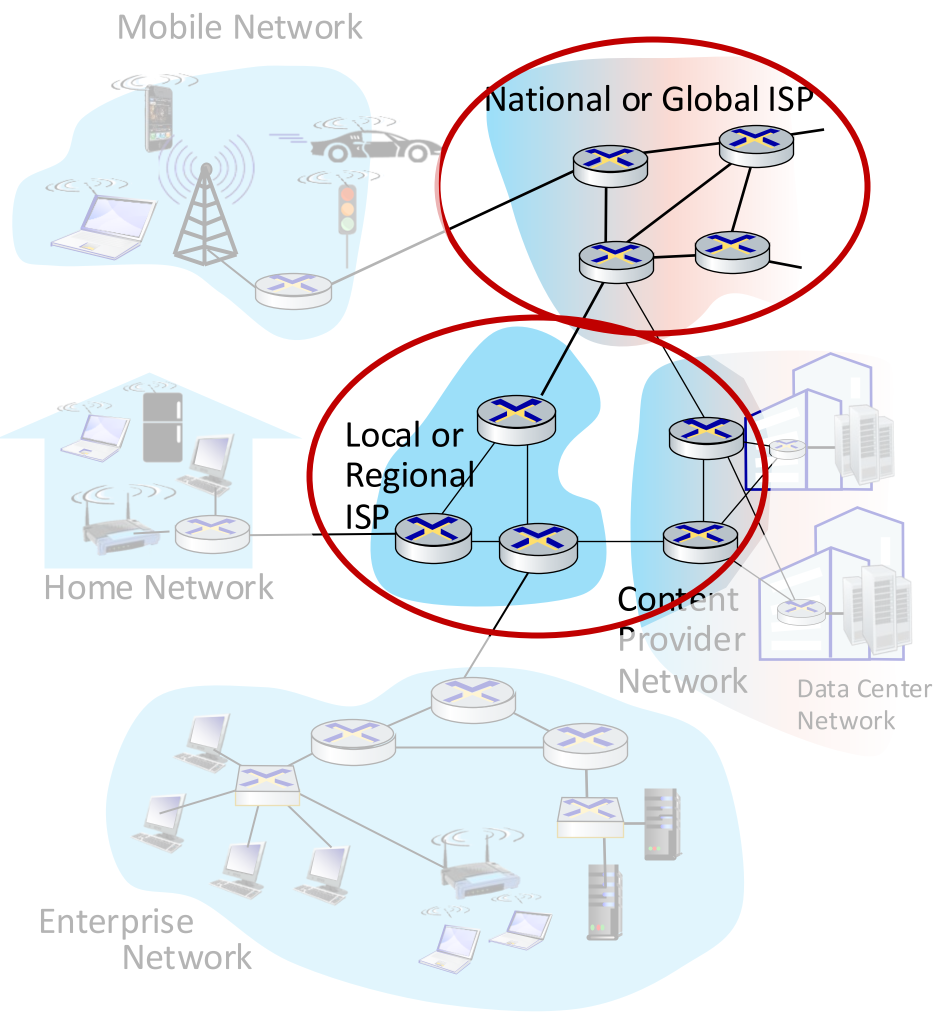
Access Media

- 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

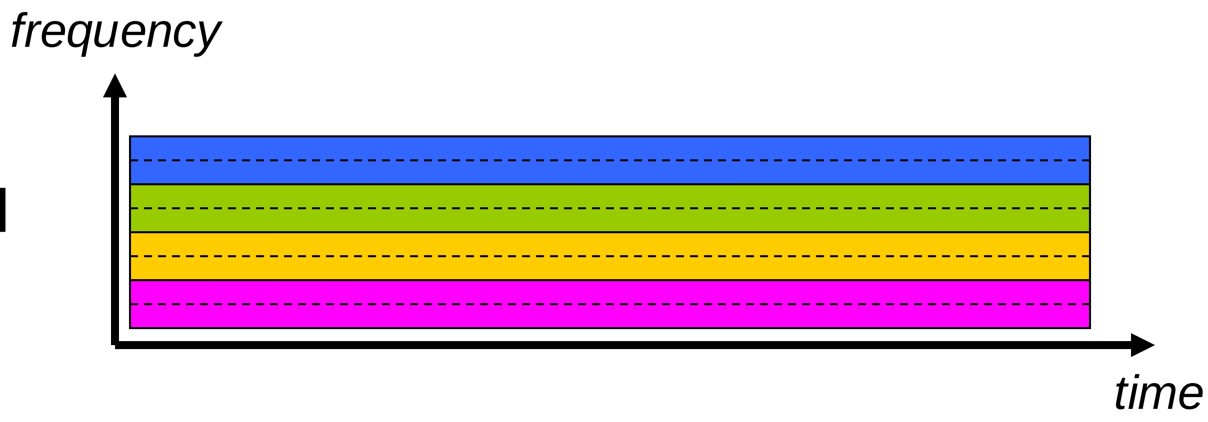


Circuit Switching

- 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

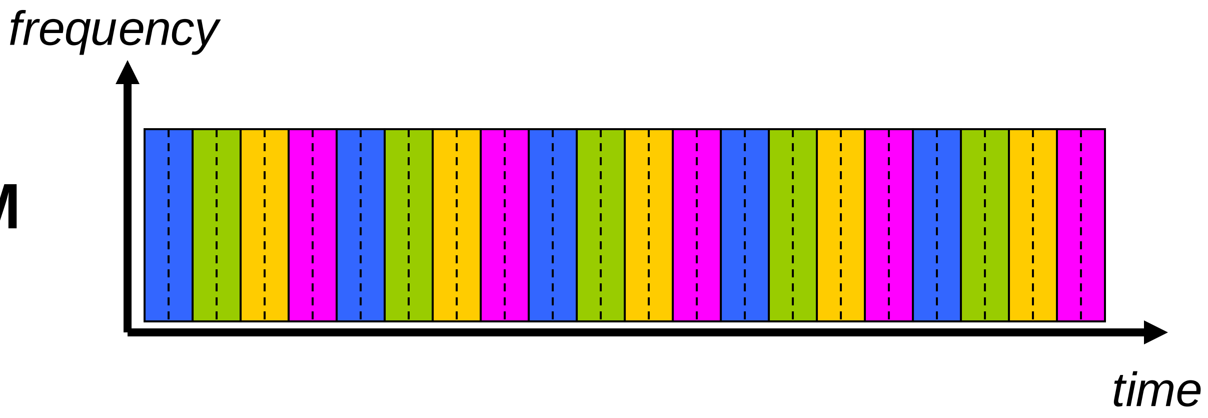
Figure (1): **FDM**



Example:

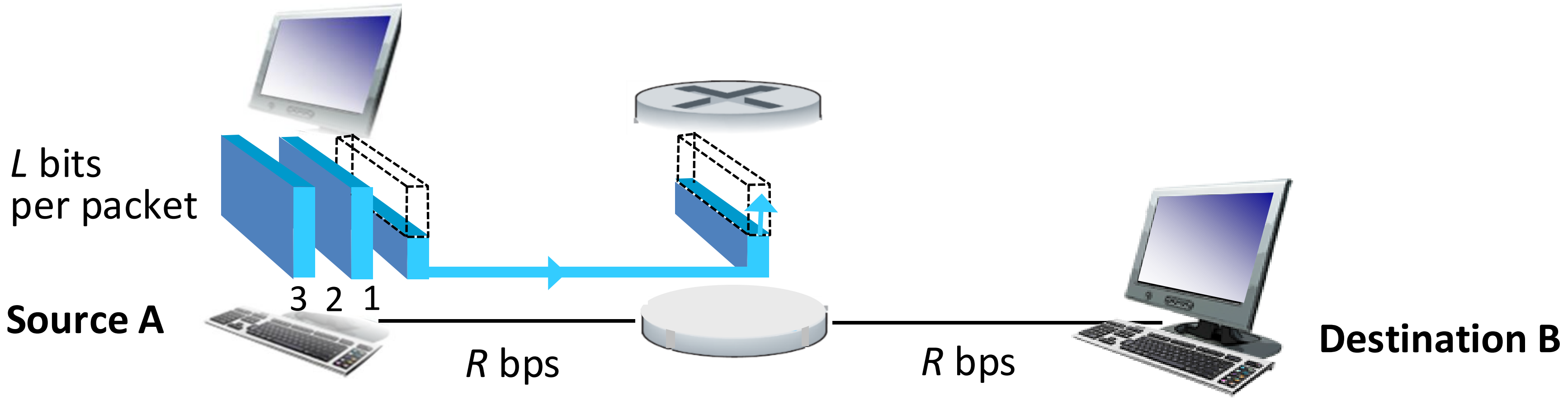
Four users **1** **2** **3** **4**

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!

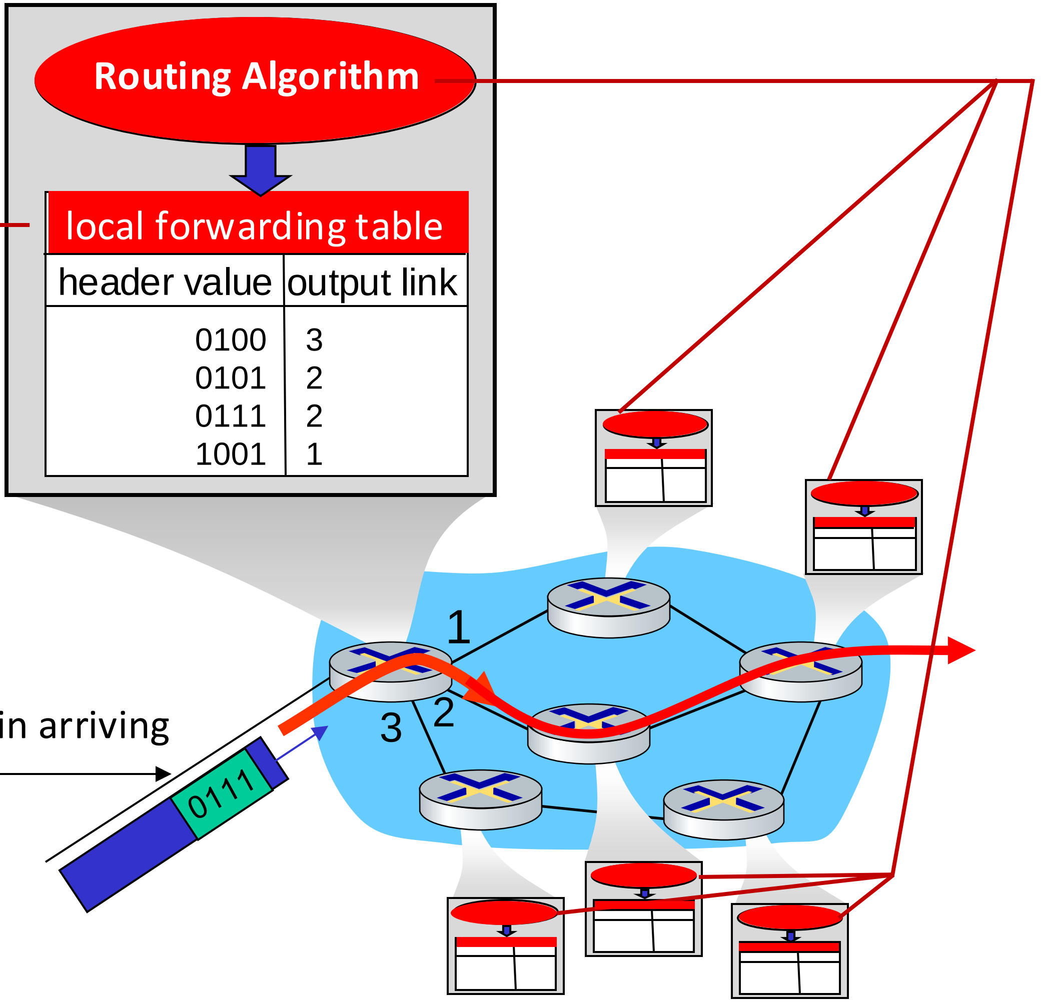
Packet Switching

- 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

Forwarding:

- Local action: Move arriving packets from router's input link to appropriate router output link



Destination address in arriving packet's header

Routing:

- Global action: Determine source-destination paths taken by packets
- Routing algorithms

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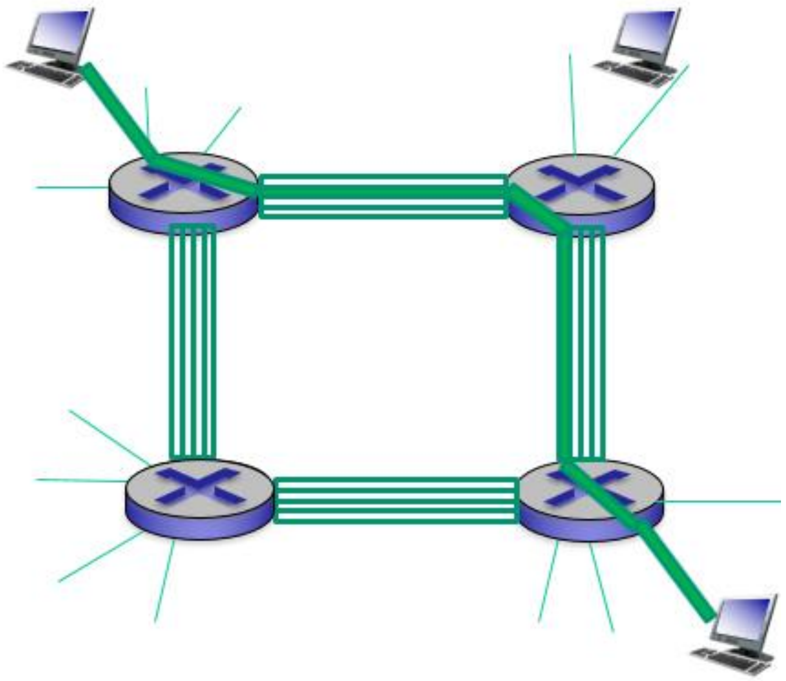
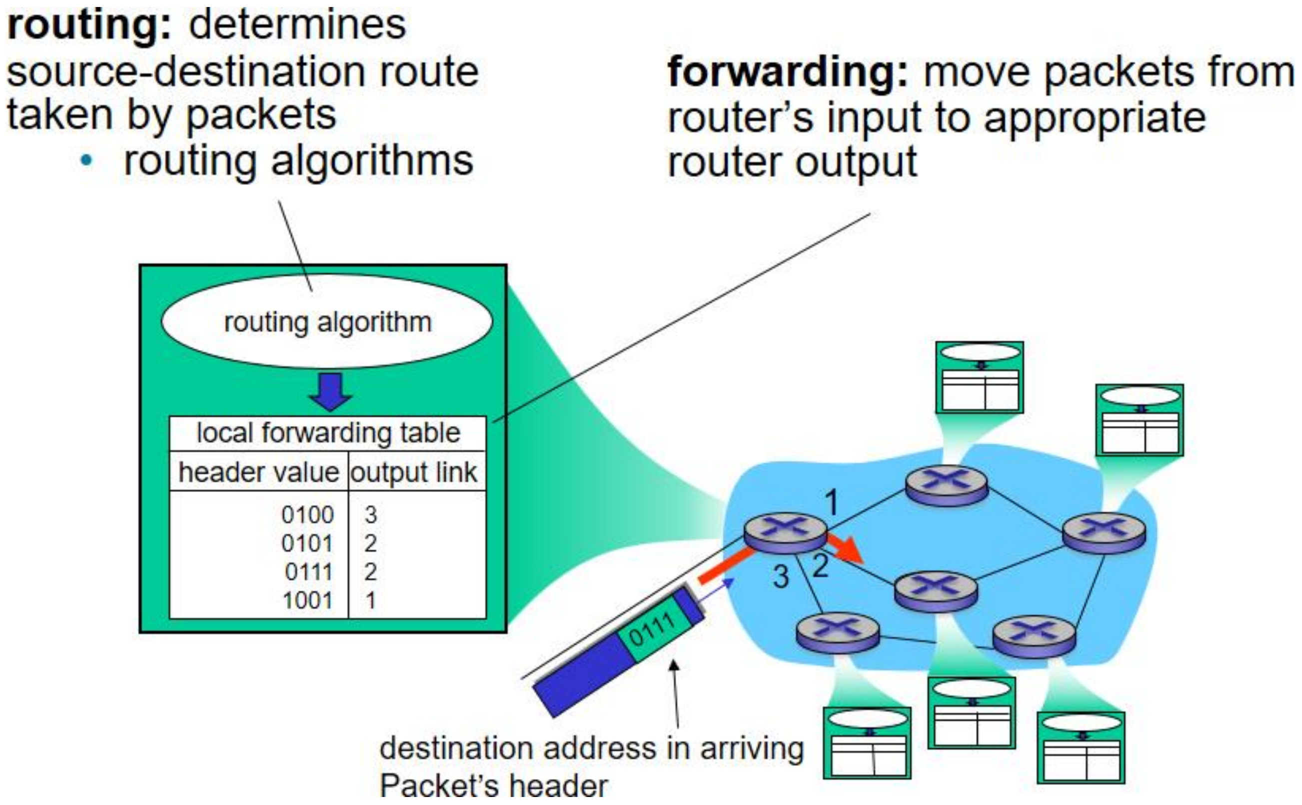
Packet Switching & Circuit Switching

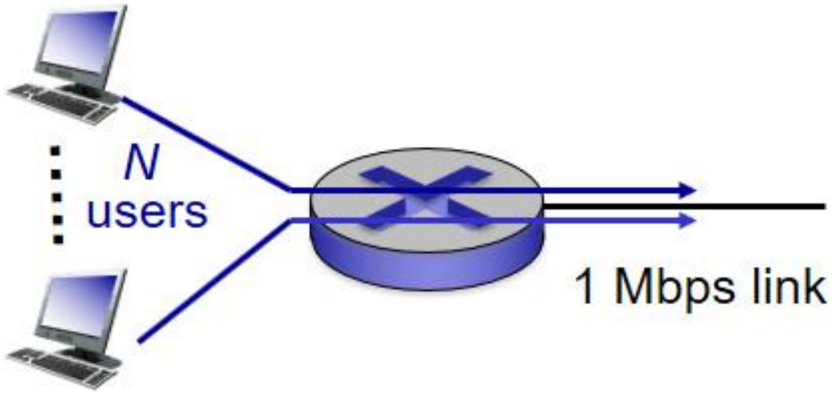
Circuit Switching



Packet Switching



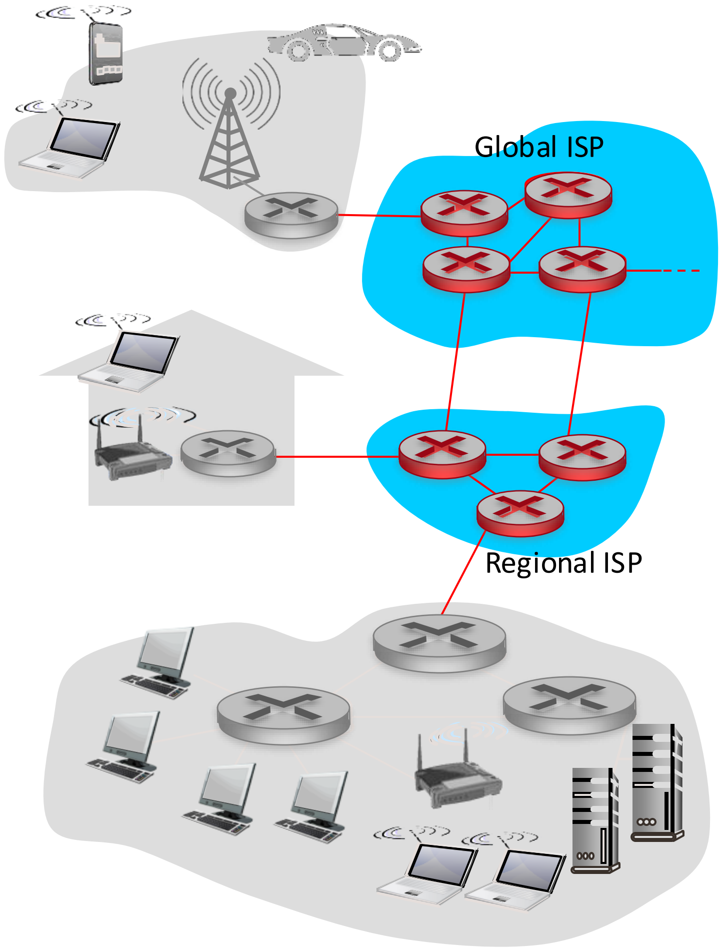
Example



- Each user **100 kbps** when active, and **active 10% of time**
- **Circuit-switching:** 10 users (1Mbps / 100 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?

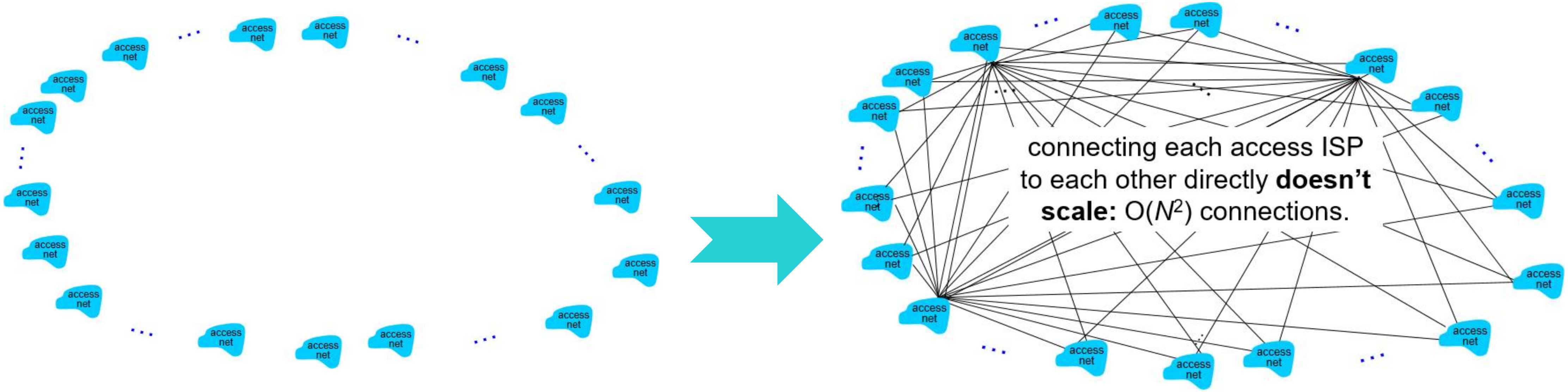
Network Core: Packet Switching

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



Internet Structure

- How to connect ISPs together?

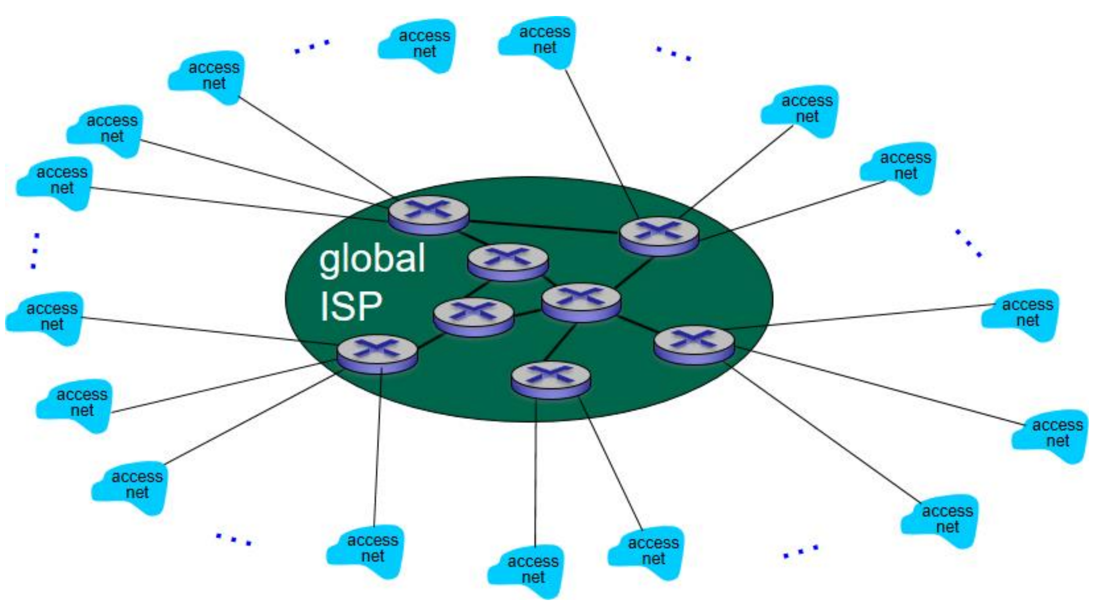


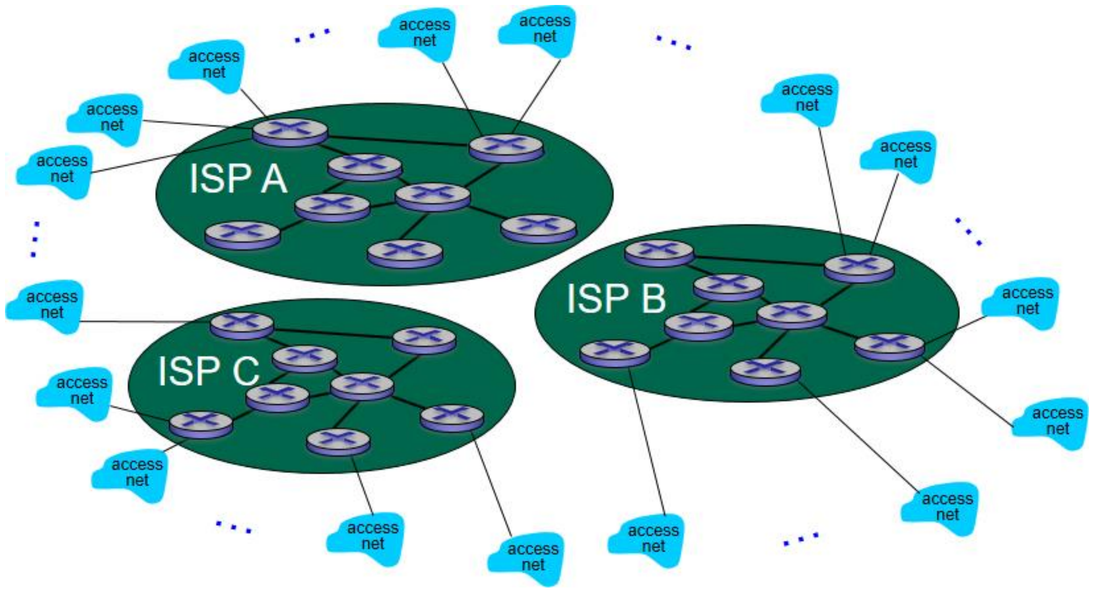
- Connect each access ISP to every other access ISP?

Internet Structure

Connect each access ISP to one global transit ISP?
Customer & provider ISPs have economic agreement.

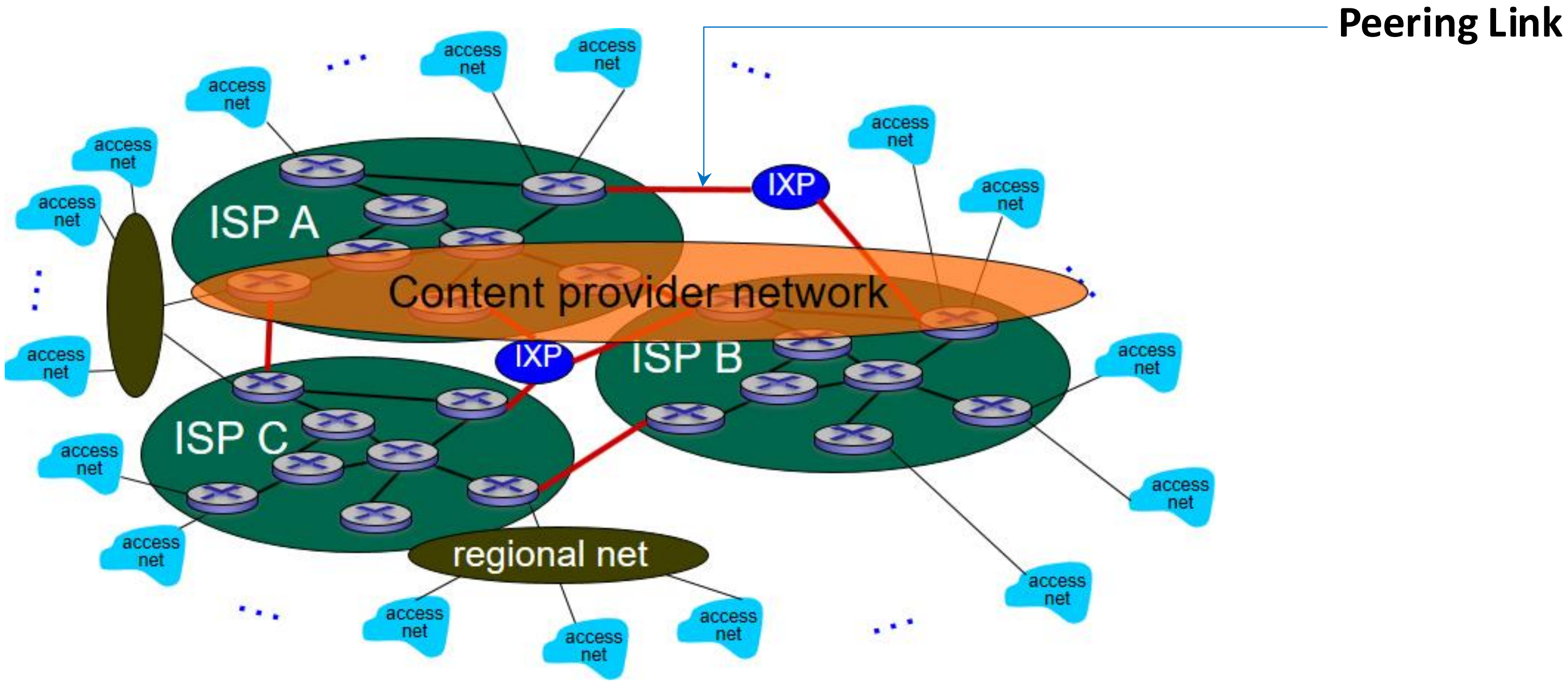
If one global ISP is a viable business,
there will be competitors!





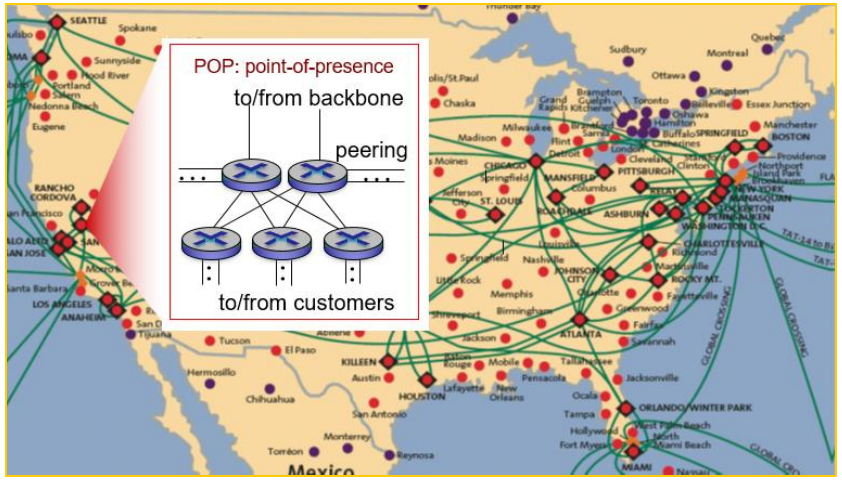
Internet Structure

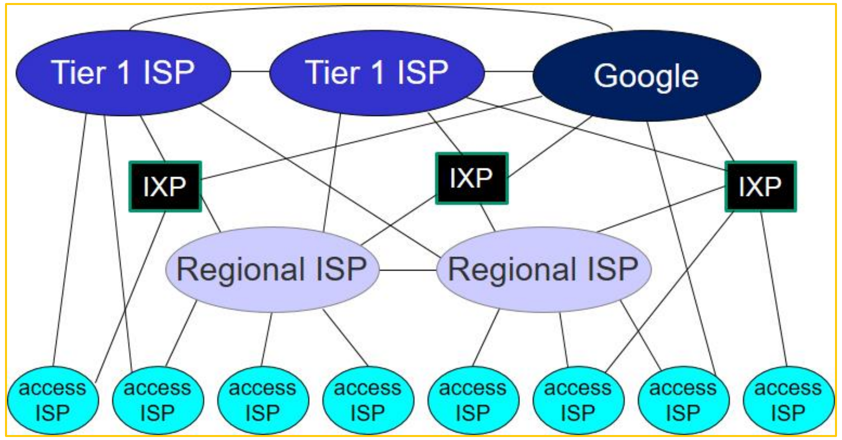
- **POP (Point of Presence):** A provider ISP's location with a group of one or more routers where customer ISPs can connect into the provider ISP
- **Regional networks** may arise to connect access nets to ISPs
- **Content provider networks** (e.g., Google, Microsoft, Akamai) may run their own network,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





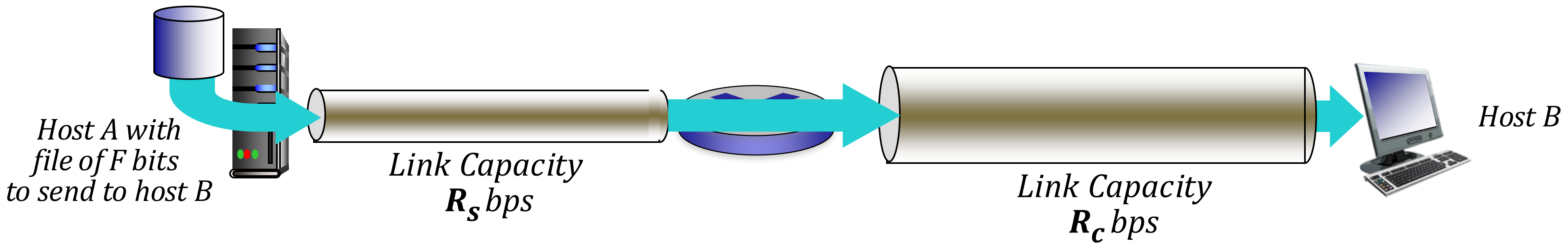
Introduction:
Network Performance

Network Performance

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

Throughput (Bandwidth)

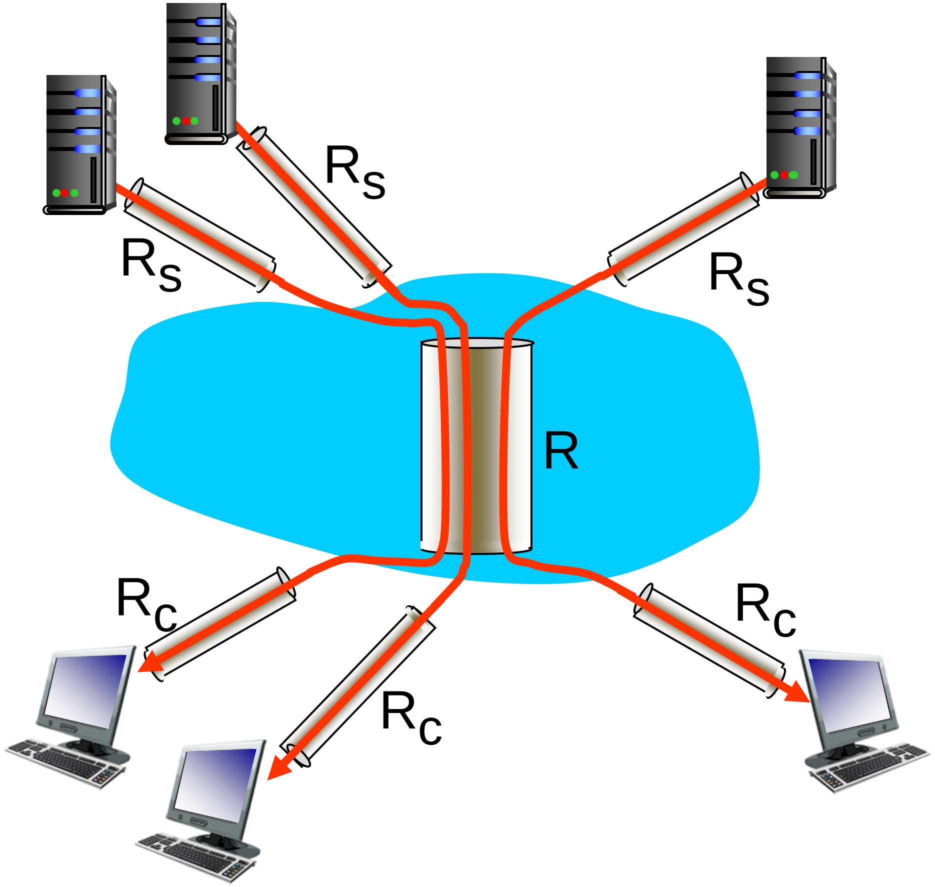
- **Throughput:** Rate (bits/time unit) at which bits transferred between sender and receiver
  - **Instantaneous:** Rate at given point in time
  - **Average:** Rate over longer period of time



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

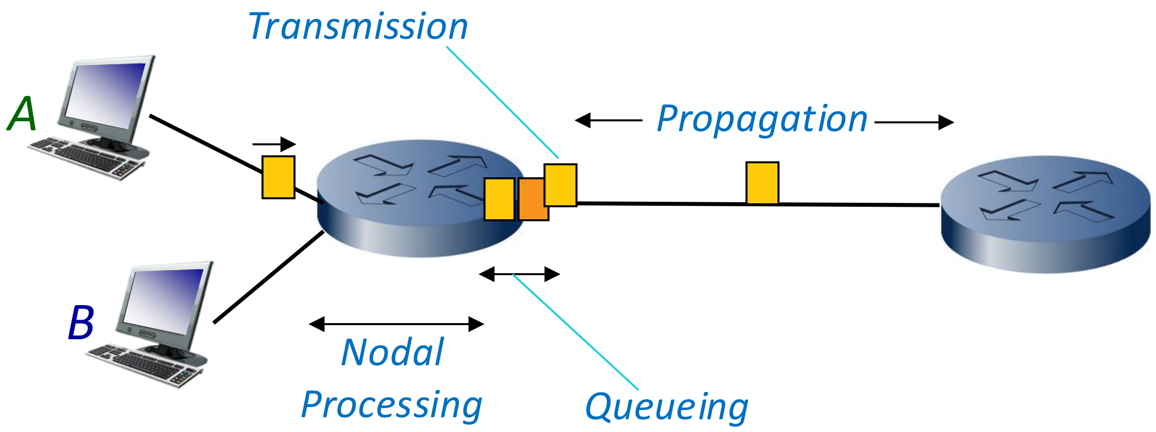
Throughput (Bandwidth)

- 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



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

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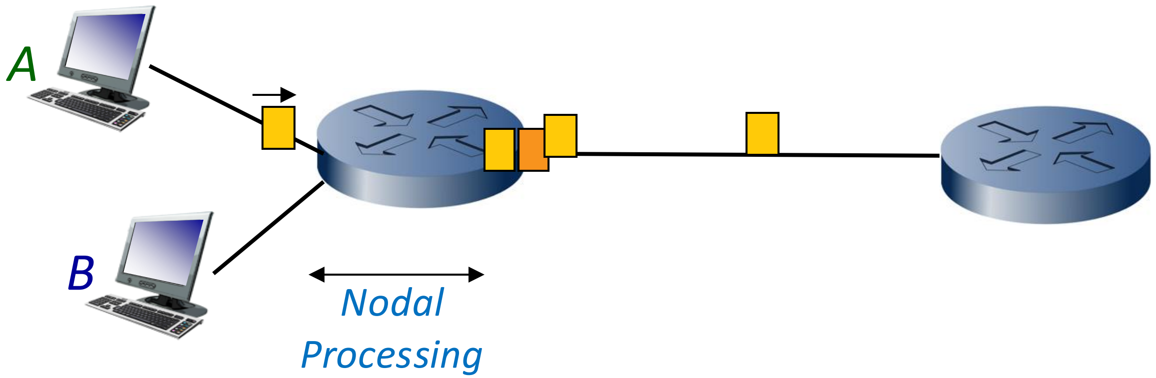
Nodal Processing Delay

- Delays due to processing on the packet in a router (d_{proc})

- Examples
  - Examining the header
  - Determining the outgoing link
  - Error checking



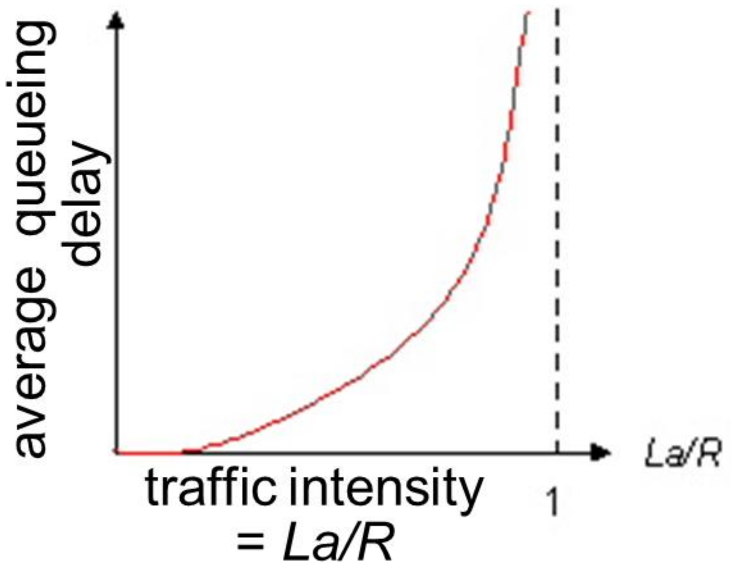
Queueing Delay

- **Traffic Intensity: La/R**
  - **R**: Link bandwidth (bps)
  - **L**: Packet length (bits)
  - **a**: Average packet arrival rate

La/R ~ 0 : Average Queuing Delay Small

La/R → 1 : Average Queuing Delay Large

La/R > 1 : More work arriving than processed



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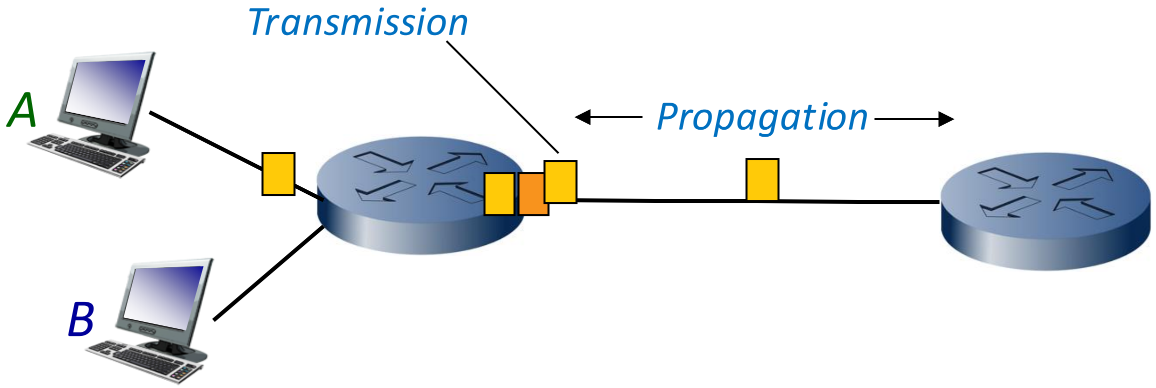
Transmission & Propagation Delays

- 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

- 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 (~$2x10^8$ m/sec)*
    - *$d_{prop} = d/s$*

  - **Nodal Procession Delay**

    d_{proc}: nodal processing
    - *Check bit errors*
    - *Determine output link*
    - *Typically < msec*

  - **Queueing Delay**

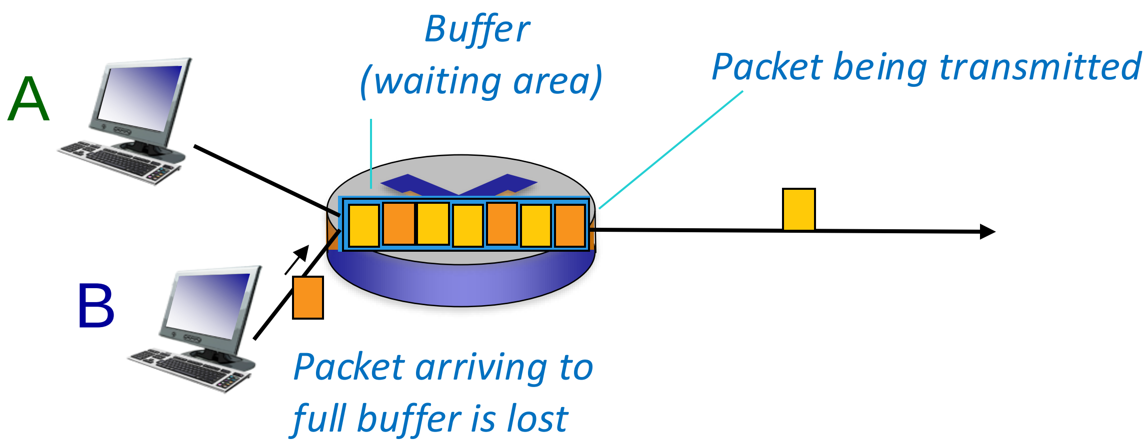
    d_{queue}: queuing delay
    - *Time waiting at output link for transmission*
    - *Depends on congestion level of router*

Jitter

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

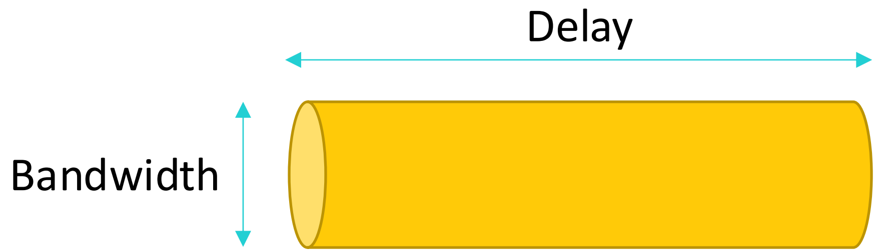
Loss (Dropped Packets)

- 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



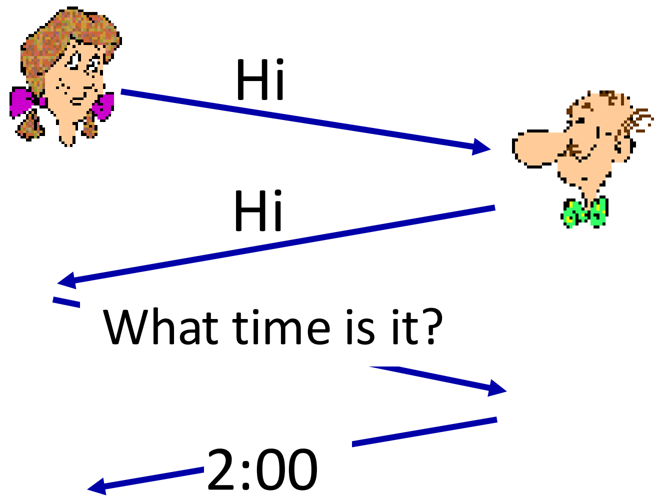
Delay × Bandwidth Product

- 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



Protocols

- 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

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

```
Internet Engineering Task Force (IETF)                  R. Fielding, Ed.
Request for Comments: 7235                                         Adobe
Obsoletes: 2616                                          J. Reschke, Ed.
Updates: 2617                                                 greenbytes
Category: Standards Track                                      June 2014
ISSN: 2070-1721


         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

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

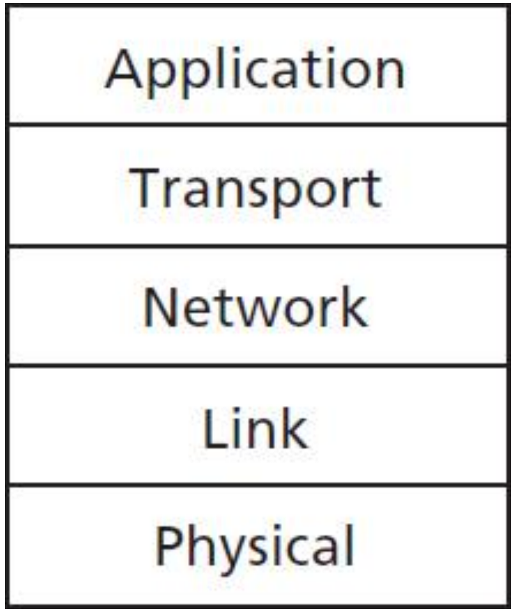
Layers: Each layer implements a service

- Via its own internal-layer actions
- Relying on services provided by layer below

- **Could layering be harmful?**

Internet Protocol Stack

- **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”



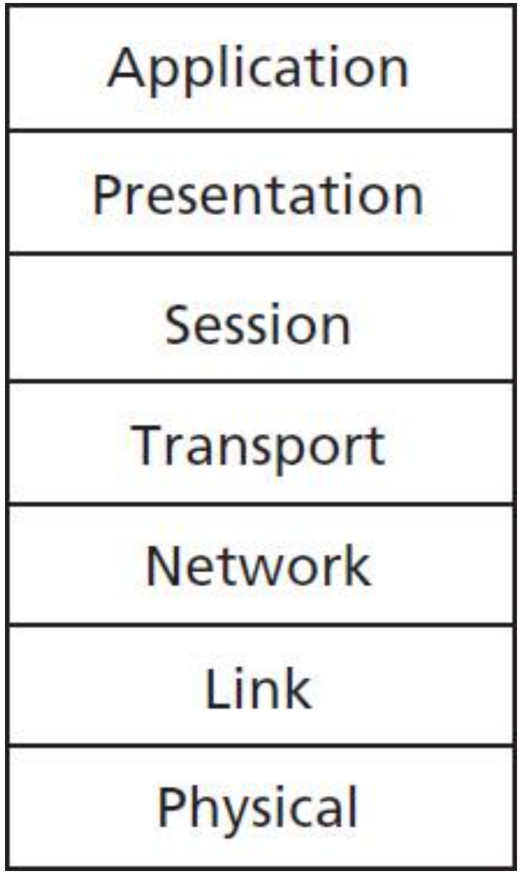
OSI/ISO Reference Model

Additional layers to Internet Protocol Stack

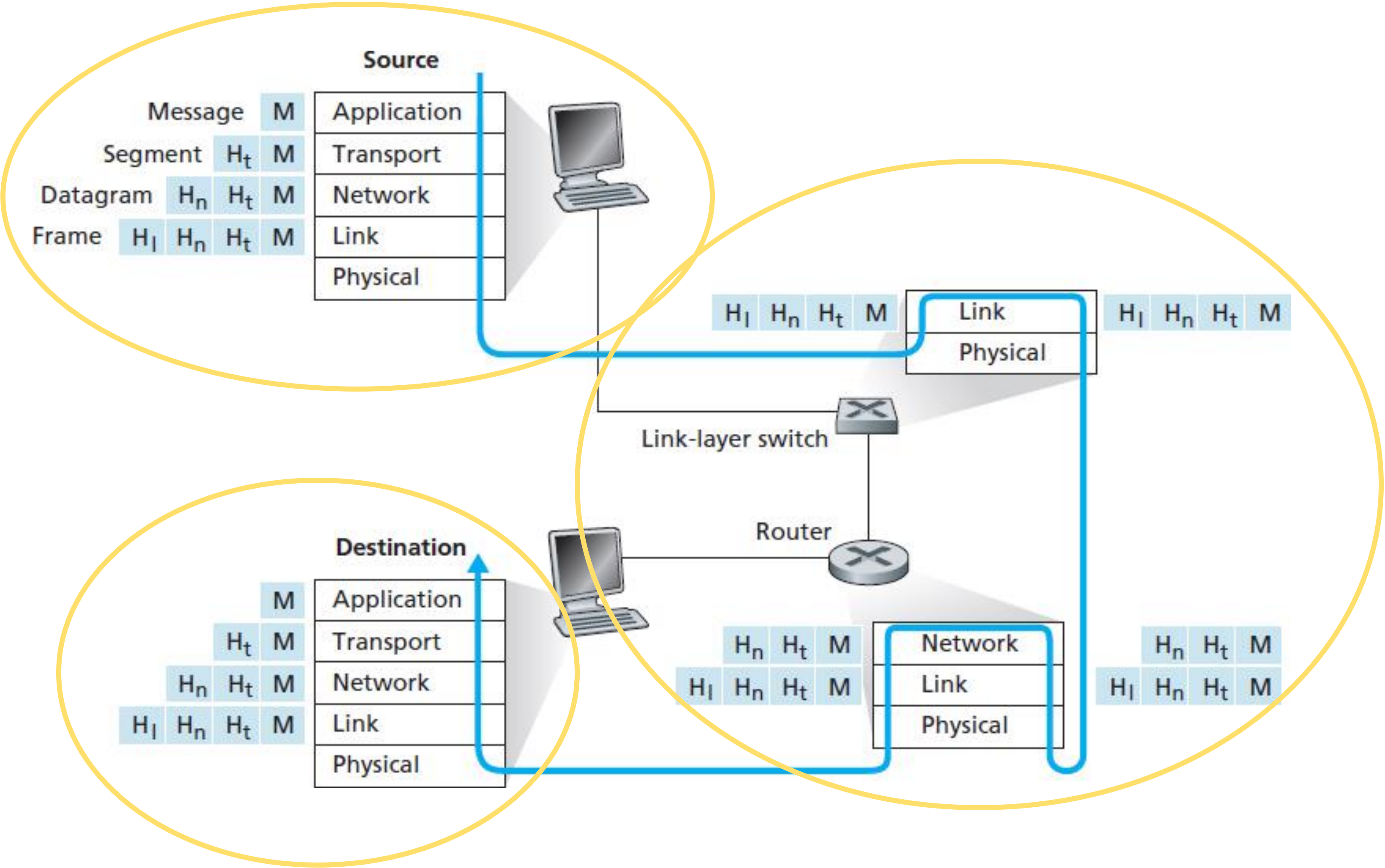
- **Presentation:** Allow applications to interpret meaning of data
  - Encryption
  - Compression
  - Machine-specific conventions

- **Session:** Synchronization, checkpointing, recovery of data exchange

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



Encapsulation



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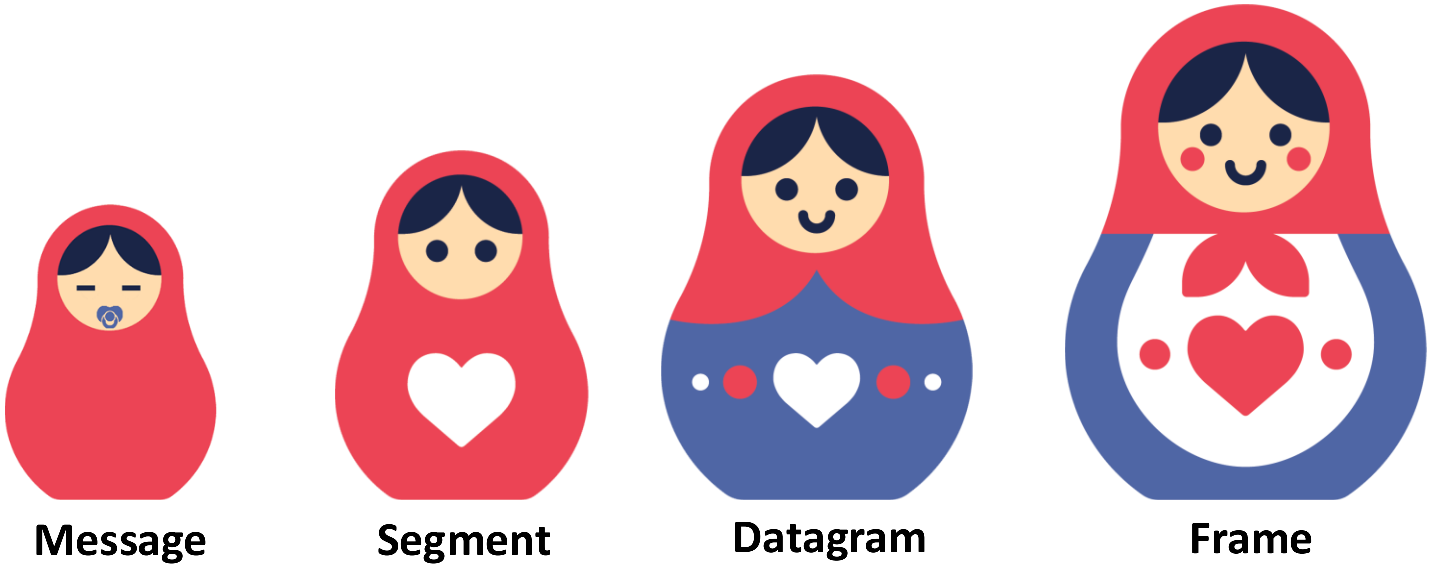
Encapsulation



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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

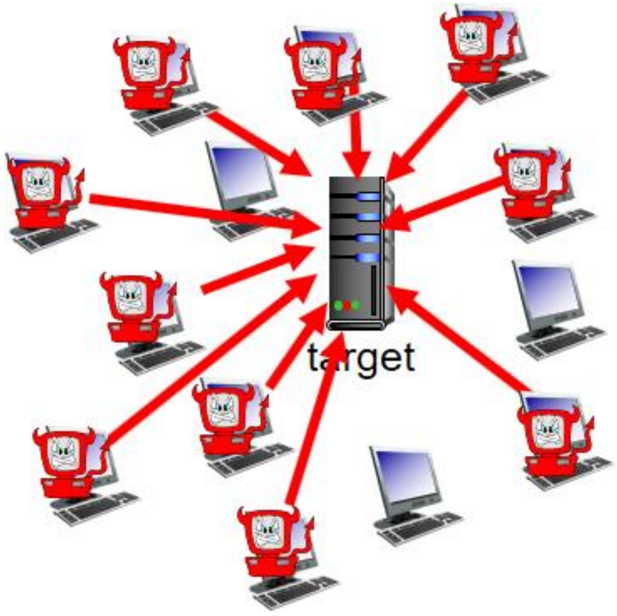
- Malware for hosts spread through the network
  - Virus: Self-replicating infection by receiving/executing object (e.g. e-mail attachment)
  - Worm: Self-replicating infection by passively receiving object that gets itself executed

- Spyware: Can record keystrokes, web sites visited, upload info to collection site

- Spoofing (IP Spoofing)

Denial of Service

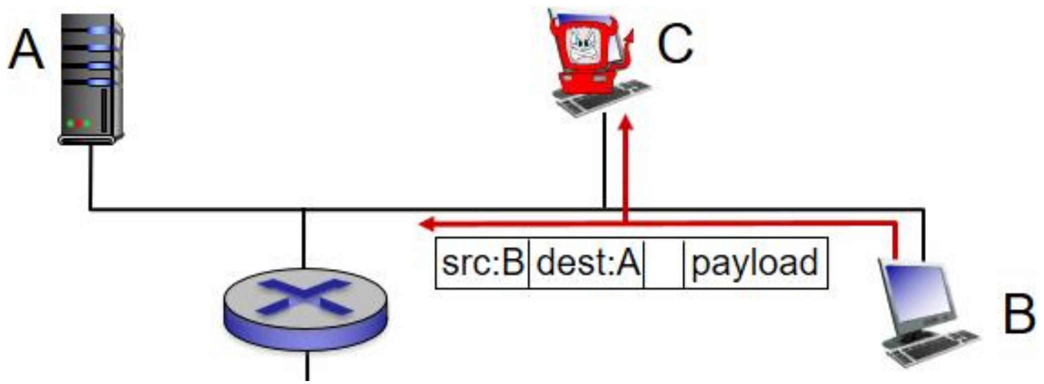
- **Denial of Service (DoS):** attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic
  - Select target
  - Break into hosts around the network (see botnet)
  - Send packets to target from compromised hosts

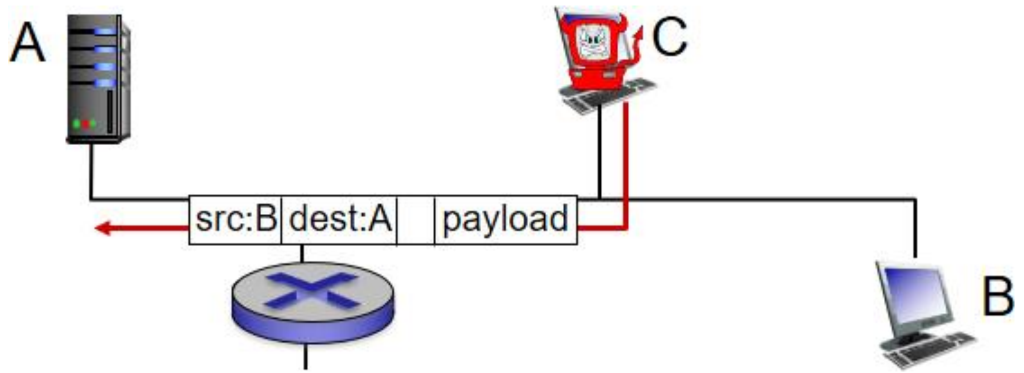


Packet Sniffing

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**

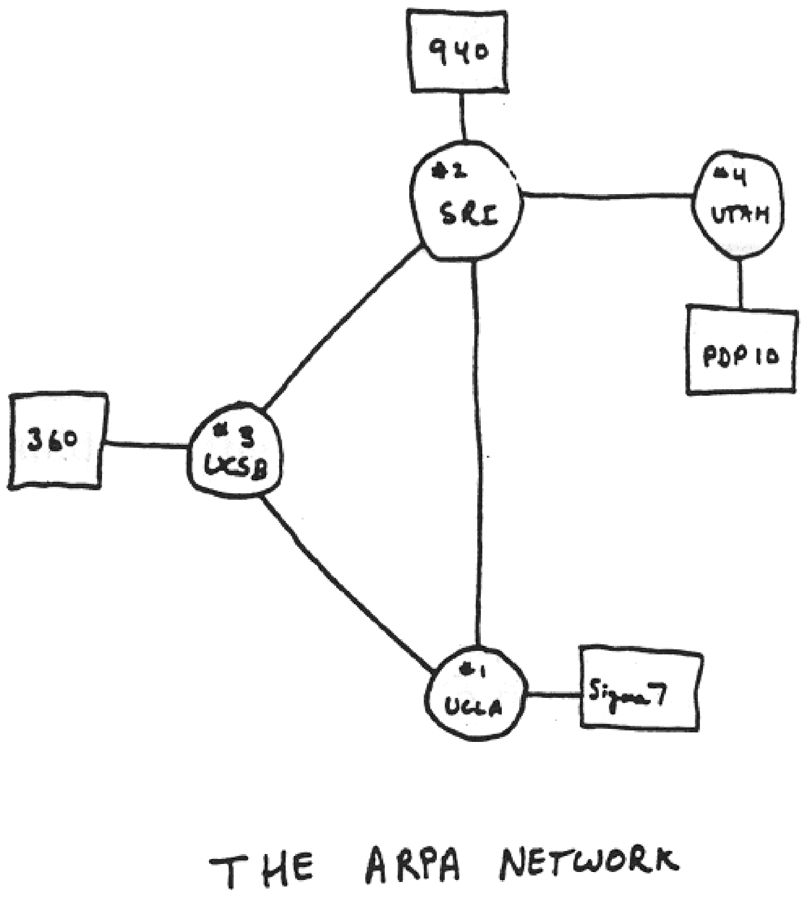
ARPANet Conceived

First **ARPANet** node

ARPANet public demo
NCP
Email

1961
1970

Packet Switching Principles



Reference: Computer Networking : A Top-Down Approach. James F. Kurose, Keith W. Ross

History of Computer Networks

Kleinrock, Queuing Theory
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ARPANet Conceived

First **ARPANet** node

ARPANet public demo
NCP
Email

TCP
UDP
IP

SMTP
FTP

TCP Congestion Control
DNS

1961 1970 1980 1990

DARPA, Telenet, Cyclades, Tymnet, etc.

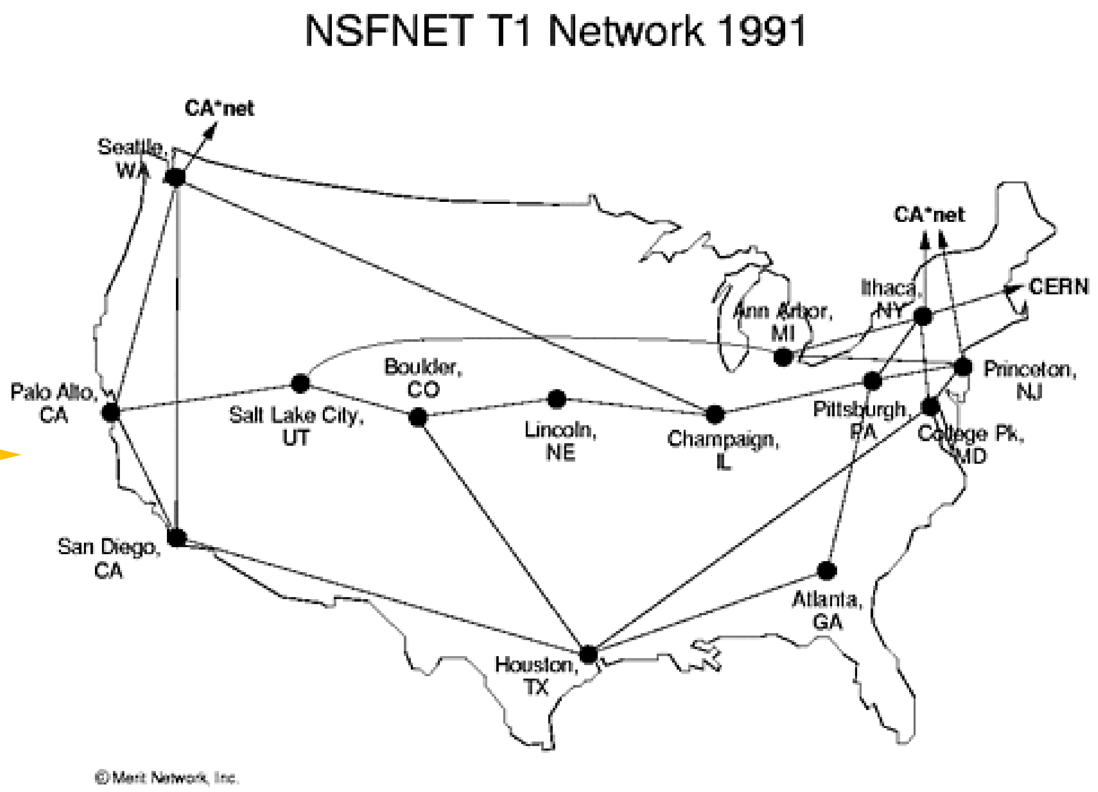
ALOHANet

TCP/IP Deployment

Packet Switching Principles

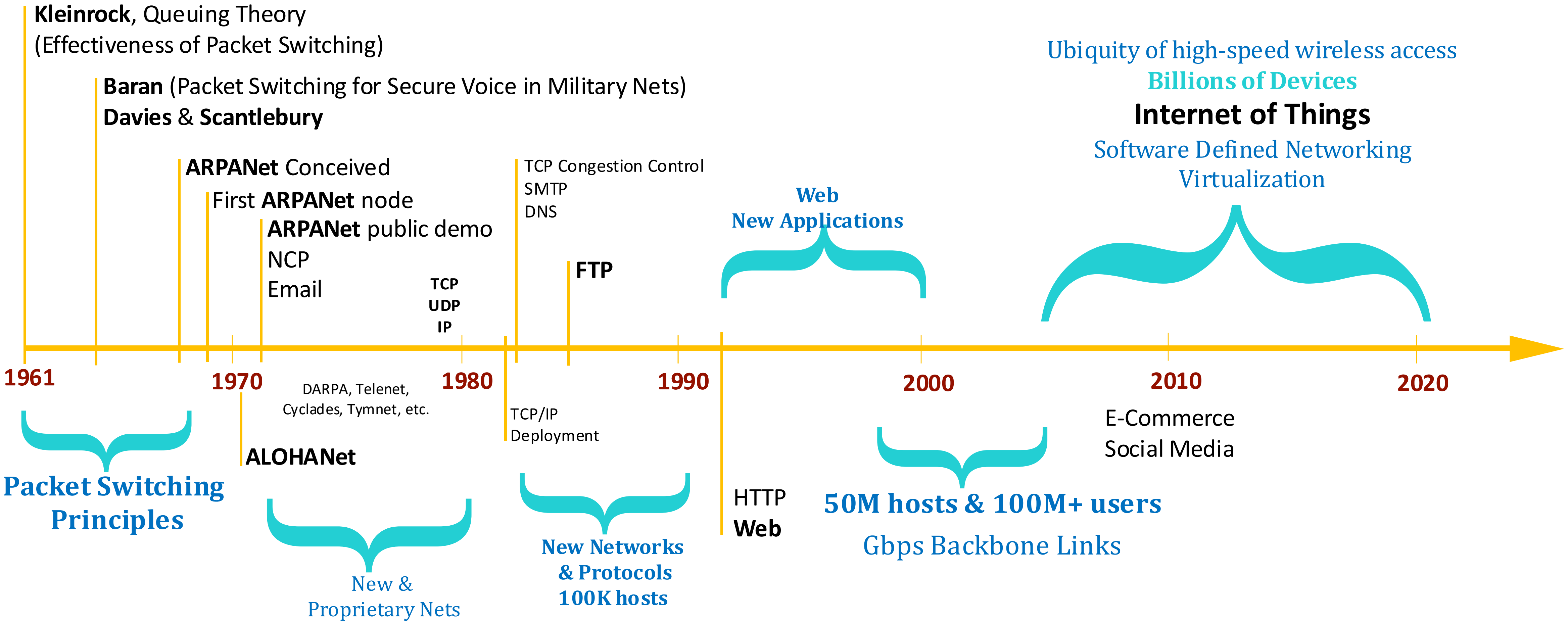
New & Proprietary Nets

New Networks & Protocols 100K hosts



Reference: Computer Networking : A Top-Down Approach. James F. Kurose, Keith W. Ross

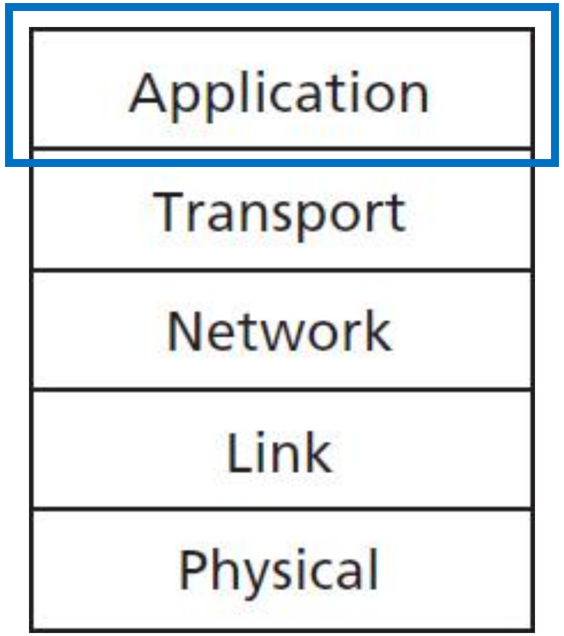
History of Computer Networks



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

Summary

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



Acknowledgements

- 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
  7th and 8th Edition, Pearson
  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/

  [2] History of Networking (Podcast)
  https://rule11.tech/history-of-networking/