

# Computer Networks and the Internet

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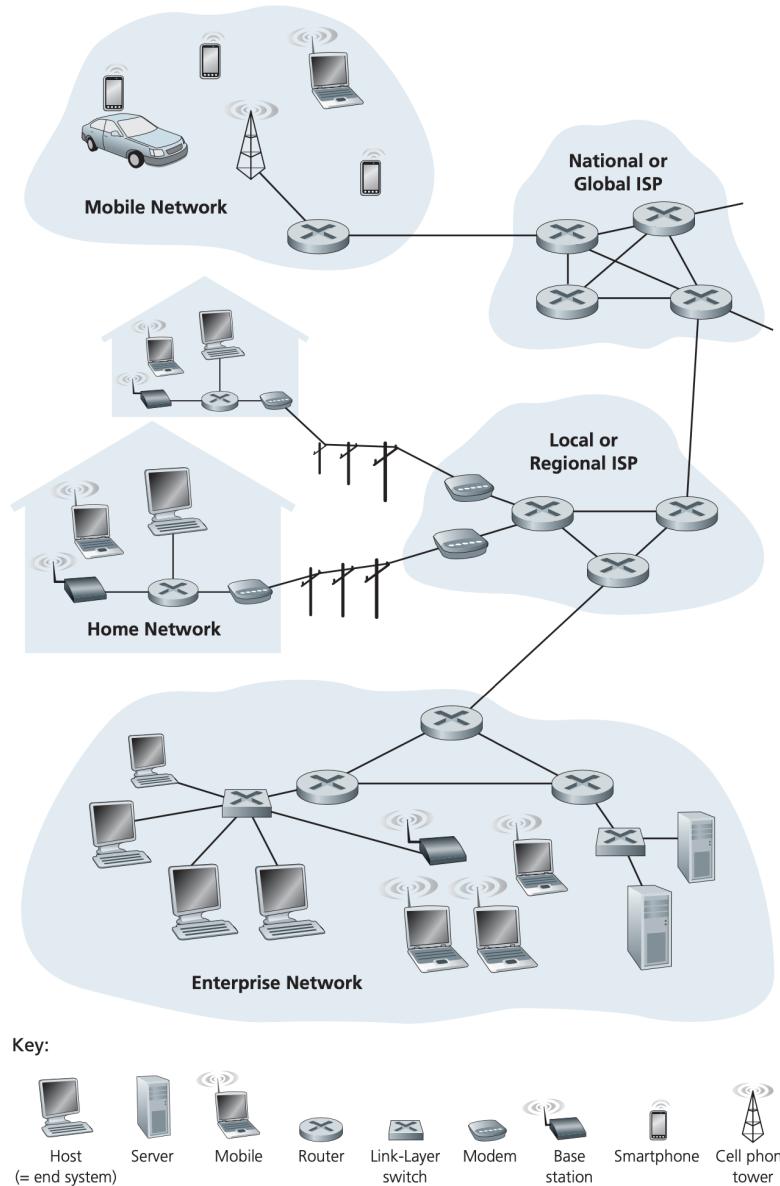
# What is the Internet?

- The Internet is a computer network that interconnects hundreds of millions of computing devices (**Hosts / End systems**) throughout the world
  - typical devices:
    - desktop PCs
    - Linux workstations
    - web or email servers
    - laptops, smartphones, tablets, TVs, automobiles, IoT devices, ...
- End systems are connected together by a network of *communication links* and *packet switches*
  - links: coaxial cable, copper wire, optical fiber, radio spectrum, ...
  - packets: segmented data with added header bytes
- A packet switch takes a packet arriving on one of its incoming communication links and *forwards* that packet on one of its outgoing communication links
  - routers (used in the network core)
  - link-layer switches (used in access networks)
- End systems access the Internet through ISPs (provide access for end systems and content providers)
  - 56Kb dial-up modem access
  - residential broadband access (cable modem / DSL)
  - wireless access
  - ...

# What is the Internet?

- End systems run protocols that **controls** the sending and receiving of information within the Internet
  - TCP/IP are the most important protocols
  - HTTP, SMTP, ICMP, UDP, ...
- Internet standards are developed by the Internet Engineering Task Force (IETF)
  - requests for comments (RFCs)
- A service description to understand Internet:
  - an *infrastructure* that provides services to apps running on end systems
  - apps do not run in the packet switches in the network core
  - end systems attached to the Internet provide an Application Programming Interface (API) that specifies how a program running on one end system asks the Internet infrastructure to deliver data to a specific destination program running on another end system

# What is the Internet?



## Some Pieces of the Internet

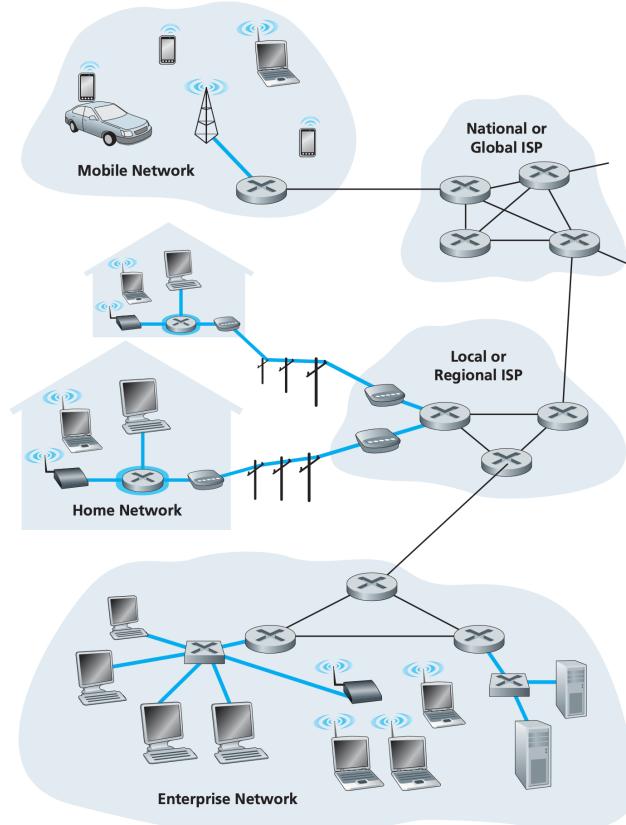
- the network edge
  - wired access
  - wireless access
- the network core
  - fiber links and routers

# What is a Protocol?

- A network protocol is similar to a human protocol, except that the entities exchanging messages and taking actions are hardware or software components of some device
  - hardware-implemented protocols in two physically connected PCs control the flow of bits on the wire between the two NICs
  - congestion control protocols control the rate at which packets are transmitted between sender and receiver
  - protocols in routers determine a packet's path from source to destination
- A FORMAL DEFINITION:
  - A protocol defines the **format** and the **order** of messages exchanged between two or more communicating entities, as well as the **actions** taken on the transmission and/or receipt of a message or other event.

# The Network Edge

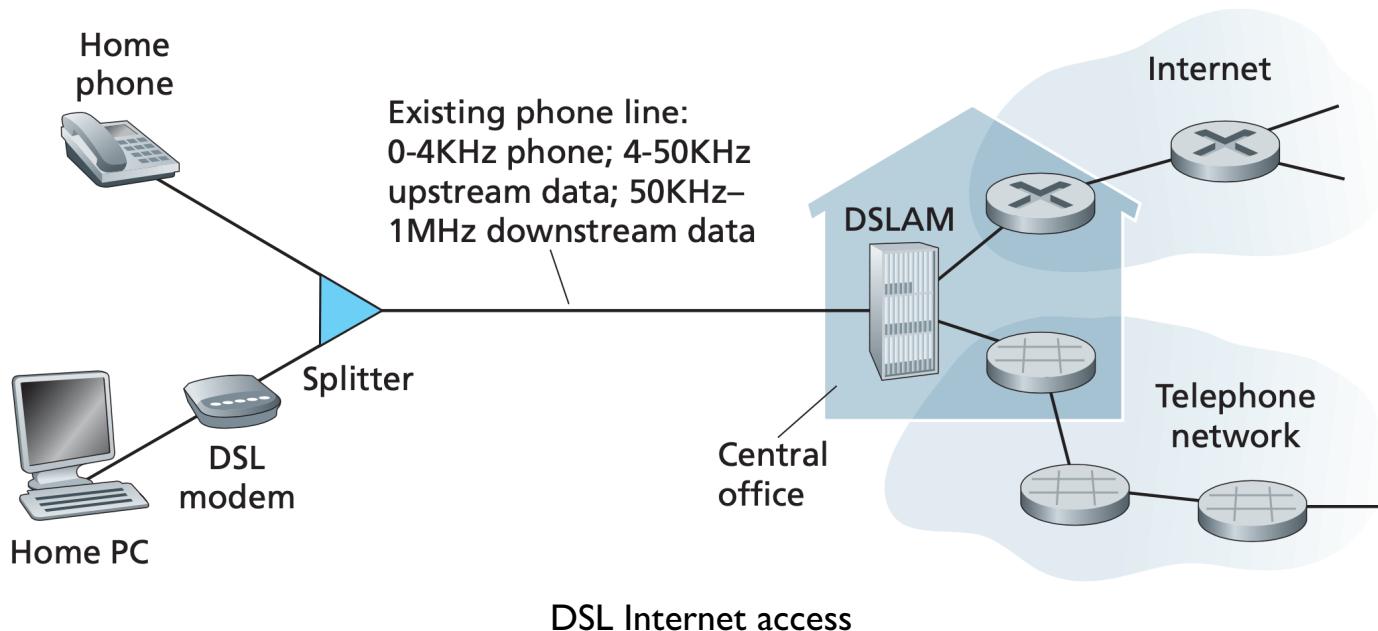
- *End systems* are also referred to as *Hosts* because they host (that is, run) application programs
  - divided into clients and servers
- Access networks is the network that physically connects an end system to *the first router* (also known as the “edge router”) on a path from the end system to any other distant end system



pay attention to these **blue** lines

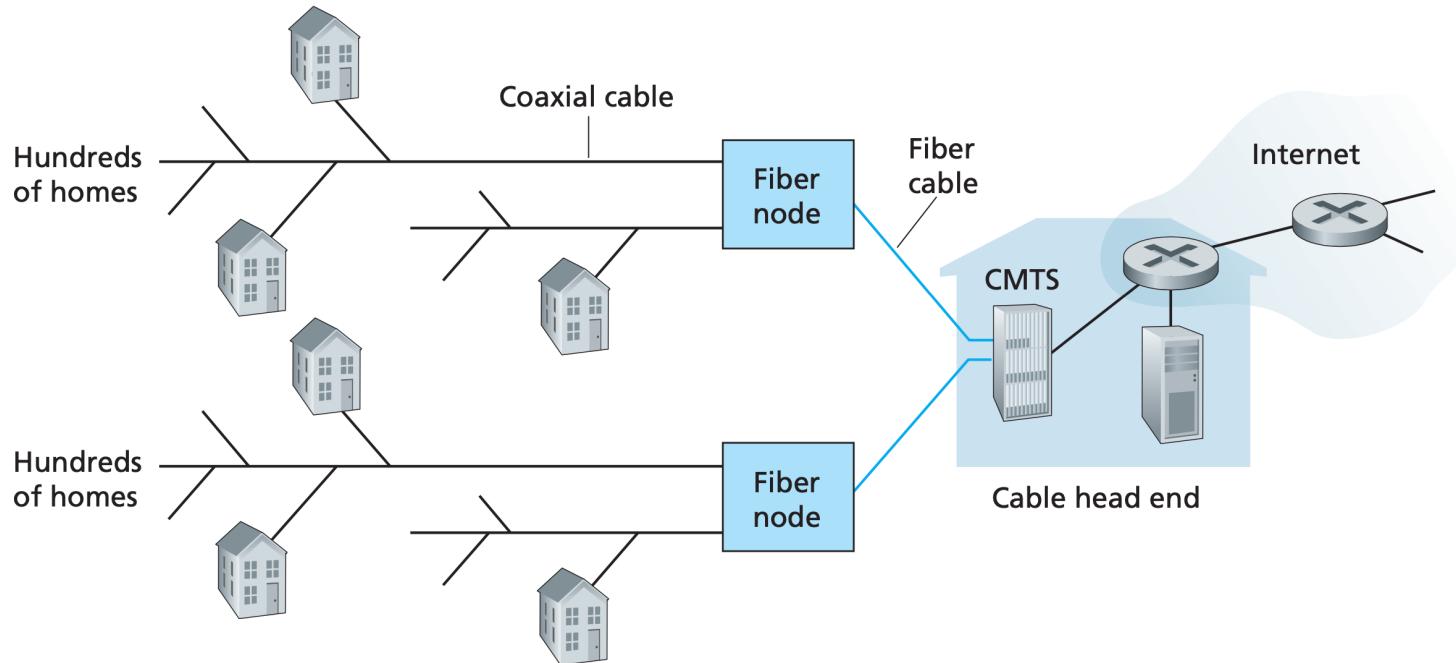
# Home Access

- Broadband residential access
  - digital subscriber line (DSL)
    - customer's DSL modem uses the existing telephone line (twisted-pair copper wire) to exchange data with a DSL access multiplexer (DSLAM) located in the telco's local central office (CO)
    - The residential telephone line carries both data and traditional telephone signals simultaneously (FDM)
    - DSL is designed for short distances between the home and the CO
    - asymmetric link rate



# Home Access

- Broadband residential access
  - cable
    - cable Internet access makes use of the cable television company's existing cable television infrastructure
    - hybrid fiber coax (HFC): fiber optics connect the cable head end to neighborhood-level junctions, from which traditional coaxial cable is then used to reach individual houses and apartments



A hybrid fiber-coaxial access network

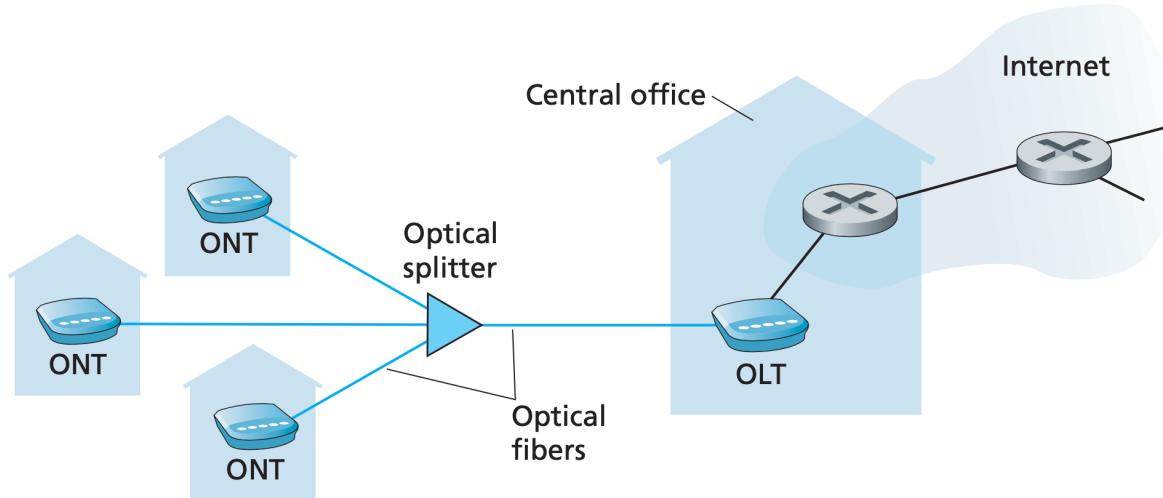
# Home Access

- Broadband residential access
  - cable (cont'd)
    - As with a DSL modem, a cable modem is typically an external device and connects to the home PC through *an Ethernet port*
    - at the cable head end, the cable modem termination system (CMTS) serves a similar function as the DSL network's DSLAM—turning the *analog signal* sent from the cable modems in many downstream homes back into *digital format*
    - a shared broadcast medium:
      - ▲ the downstream rate is shared
      - ▲ the upstream channel is also shared (a distributed multiple access protocol is needed to coordinate transmissions and avoid collisions)

DSL and cable Internet access are out-of-date now → FTTH

# Home Access

- Fiber to the home (FTTH)
  - provide an optical fiber path from the CO directly to the home
  - each fiber leaving the central office is shared by many homes
  - it is not until the fiber gets relatively close to the homes that it is split into individual customer-specific fibers
    - active optical networks (AONs): is essentially switched *Ethernet*
    - passive optical networks (PONs)
      - ▲ the OLT, providing conversion between optical and electrical signals, connects to the Internet via a telco router
      - ▲ users connect a home router (typically a wireless router) to the ONT and access the Internet via this home router



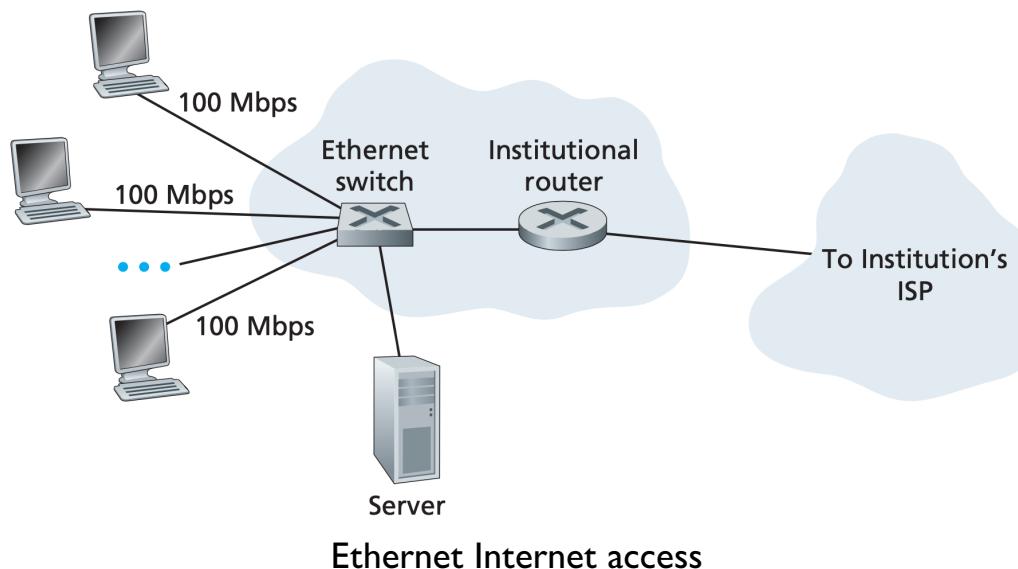
FTTH using PON architecture

# Home Access

- Satellite
  - StarBand, HughesNet, StarLink ...
- Dial-up access
  - based on the same model as DSL—a home modem connects over a phone line to a modem in the ISP
  - over traditional phone lines

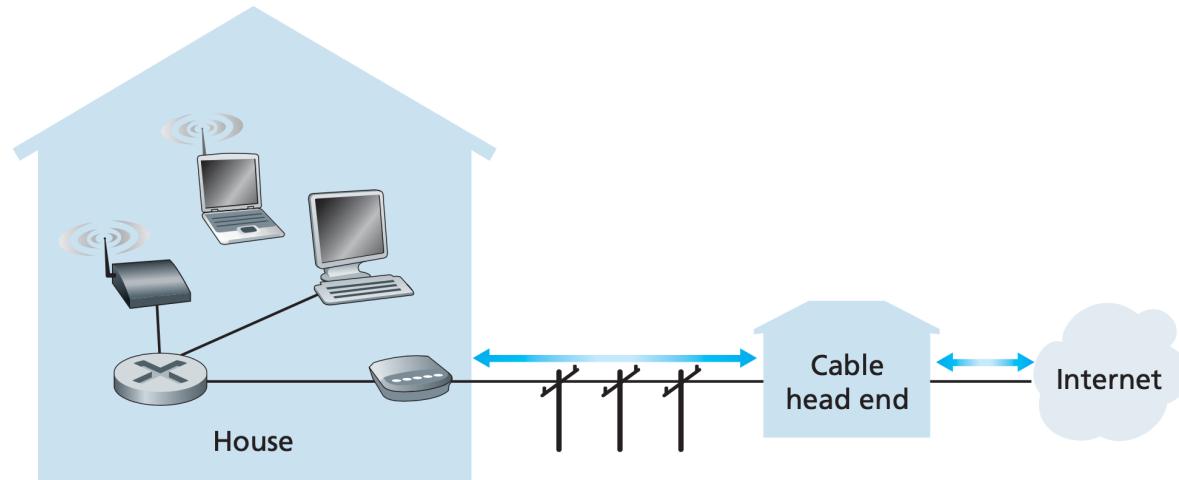
# Access in the Enterprise (and the Home)

- A local area network (LAN) is used to connect an end system to the edge router
- Ethernet is by far the most prevalent access technology for LAN
  - Ethernet users use twisted-pair copper wire to connect to an Ethernet switch
- In a wireless LAN setting, wireless users transmit/receive packets to/from an access point that is connected into the enterprise's network (most likely including wired Ethernet), which in turn is connected to the wired Internet
  - Wireless LAN access based on IEEE 802.11 technology, more colloquially known as WiFi



# Access in the Enterprise (and the Home)

- Many homes combine broadband residential access (that is, cable modems or DSL) with these inexpensive wireless LAN technologies to create powerful home networks

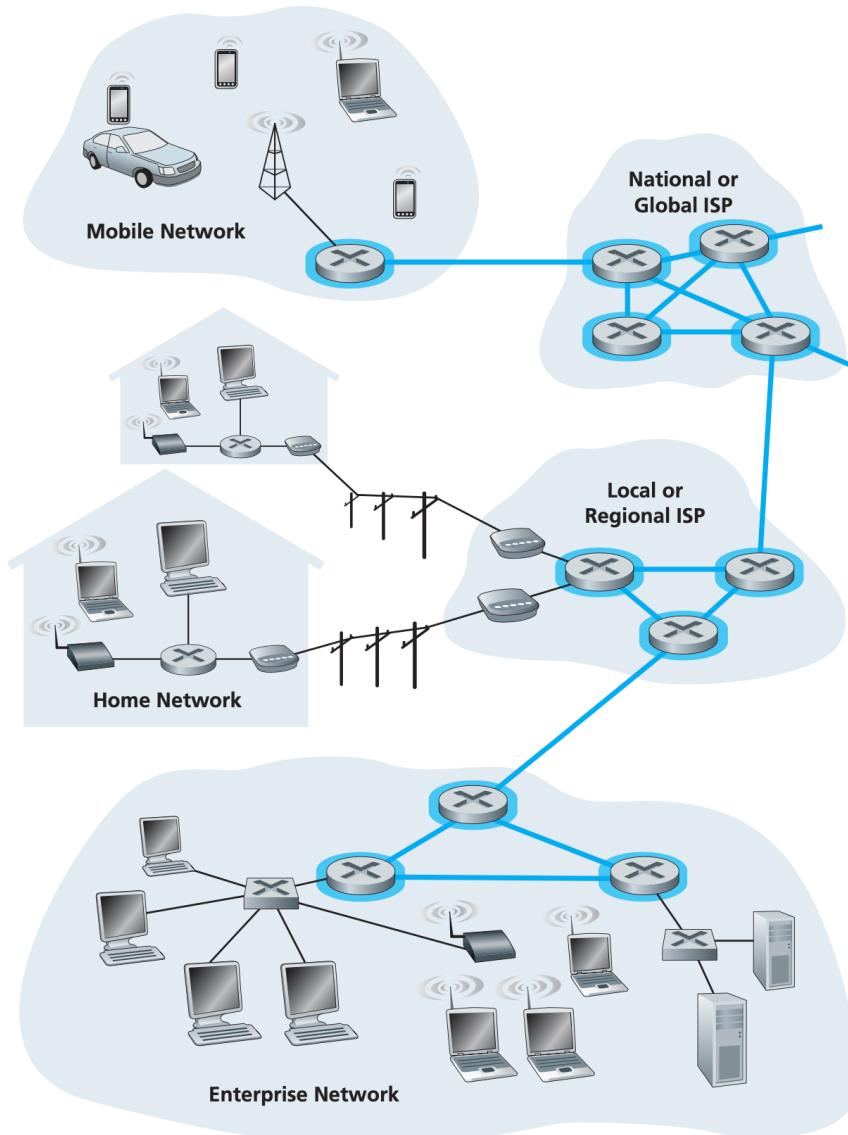


A typical home network nowadays

# Physical Media

- For each transmitter-receiver pair, the bit is sent by propagating electromagnetic waves or optical pulses across a physical medium
  - guided media (a fiber-optic cable, a twisted-pair copper wire, or a coaxial cable)
    - Twisted-Pair Copper Wire: has emerged as the dominant solution for high-speed LAN networking
    - Coaxial Cable: commonly used in cable television systems
    - Fiber Optics: commonly used for long-haul guided transmission, also prevalent in the backbone of the Internet
  - unguided media (the waves propagate in the atmosphere and in outer space)
    - Terrestrial Radio Channels: depend significantly on the propagation environment and the distance over which a signal is to be carried
      - ▲ path loss, shadow fading, multipath fading, interference
      - ▲ BlueTooth, WiFi, cellular network
    - Satellite Radio Channels: links two or more Earth-based microwave transmitter/ receivers, known as ground stations

# The Network Core

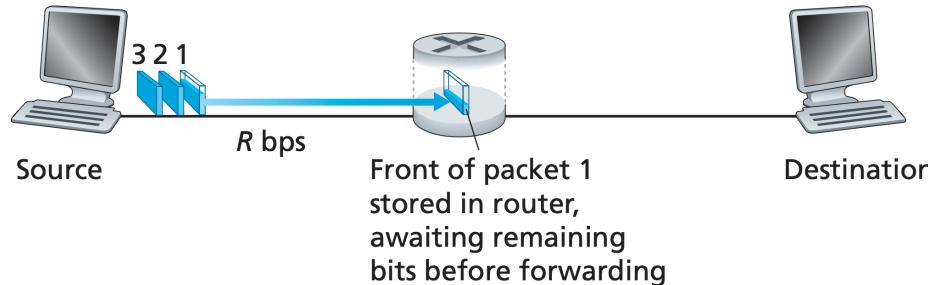


- **Packet switching**
  - Store-and-Forward Transmission
  - Queuing Delays and Packet Loss
  - Forwarding Tables and Routing Protocols
- **Circuit switching**
  - Multiplexing in Circuit-Switched Networks
- **A network of networks**

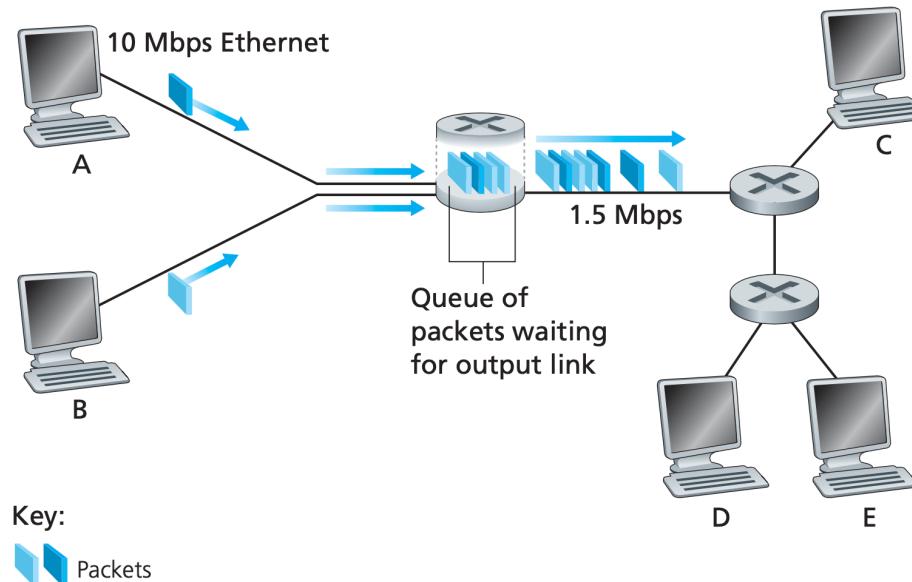
The network core: pay attention to these blue lines

# Packet Switching

- Store-and-forward transmission
  - routers need to receive, store, and process the entire packet before forwarding



- Packet switching example
  - packets from different sources queue in the buffer according to the arrival order

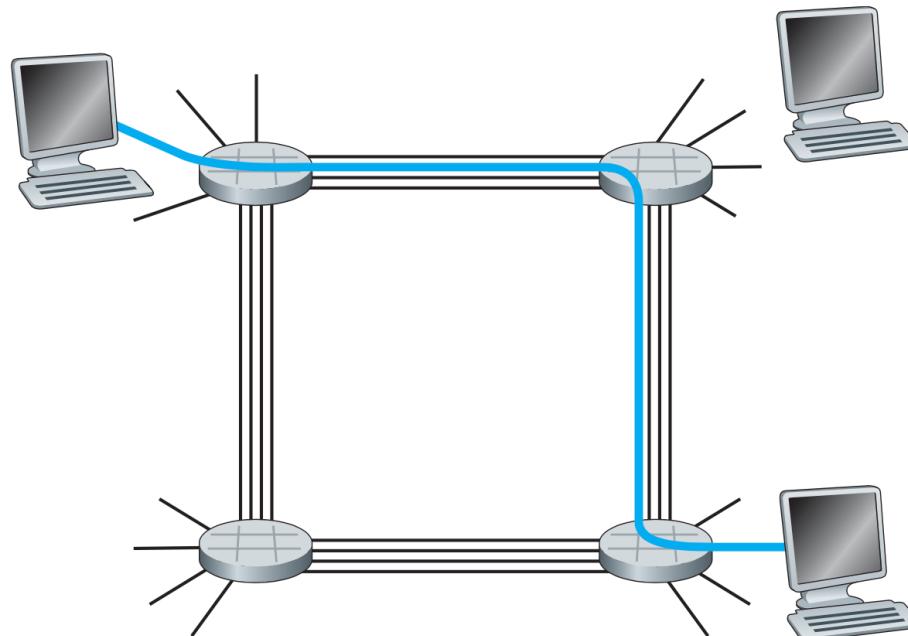


# Packet Switching

- Forwarding tables
  - every end system has an address called an IP address
  - each router has a forwarding table that maps destination addresses (or portions of the destination addresses) to that router's outbound links
  - the end-to-end routing process is analogous to a car driver who does not use maps but instead prefers to *ask for directions*
  - the Internet has a number of special routing protocols that are used to automatically set the forwarding tables

# Circuit Switching

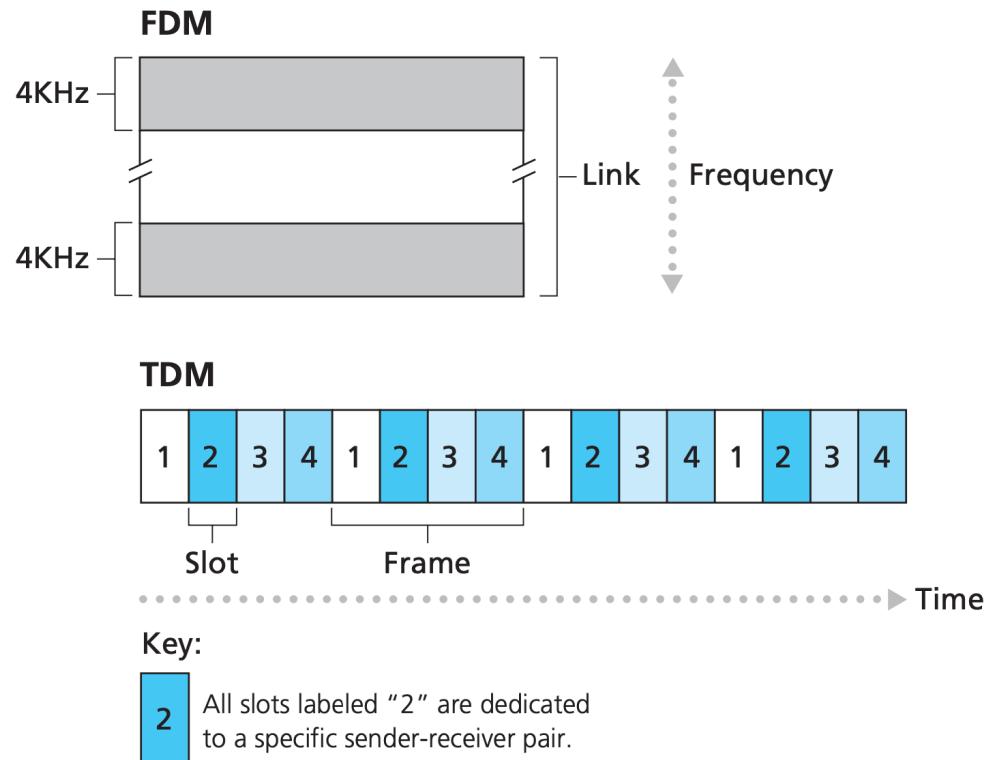
- In circuit-switched networks, the resources needed along a path (buffers, link transmission rate) to provide for communication between the end systems are **reserved** for the duration of the communication session between the end systems
  - when the network establishes the circuit, it also reserves a constant transmission rate in the network's links for the duration of the connection
  - a dedicated end-to-end connection



A simple circuit-switched network consisting of four switches and four links

# Circuit Switching

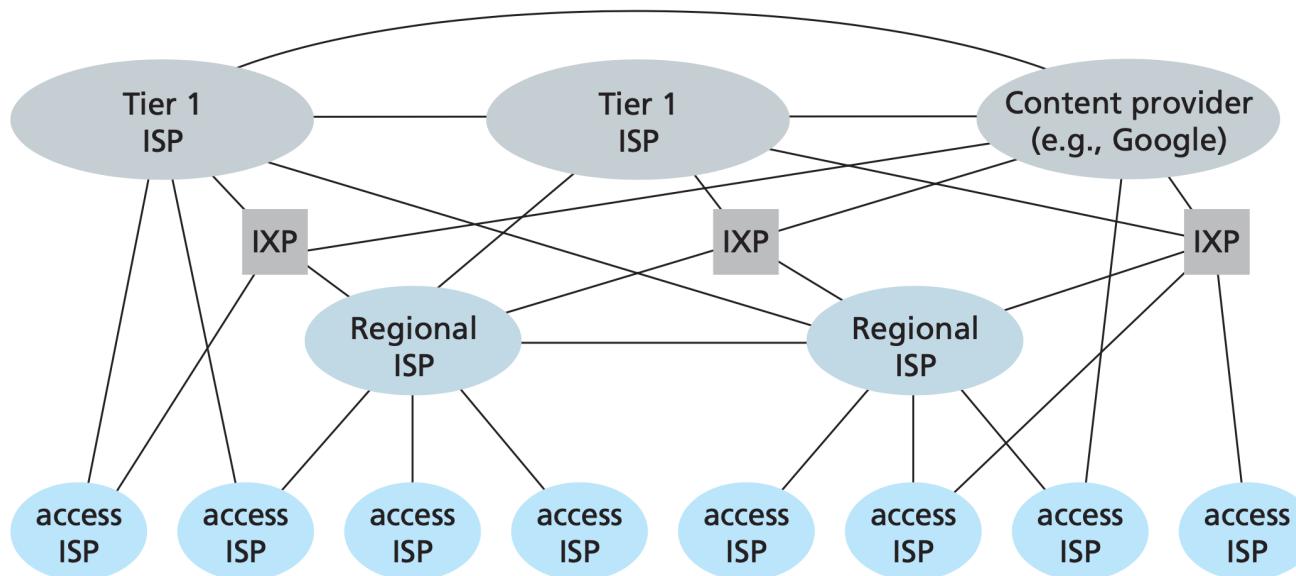
- Multiplexing
  - frequency-division multiplexing (FDM)
  - time-division multiplexing (TDM)
- circuit switching is wasteful because the dedicated circuits are idle during silent periods



With FDM, each circuit continuously gets a fraction of the bandwidth. With TDM, each circuit gets all of the bandwidth periodically during brief intervals of time (that is, during slots)

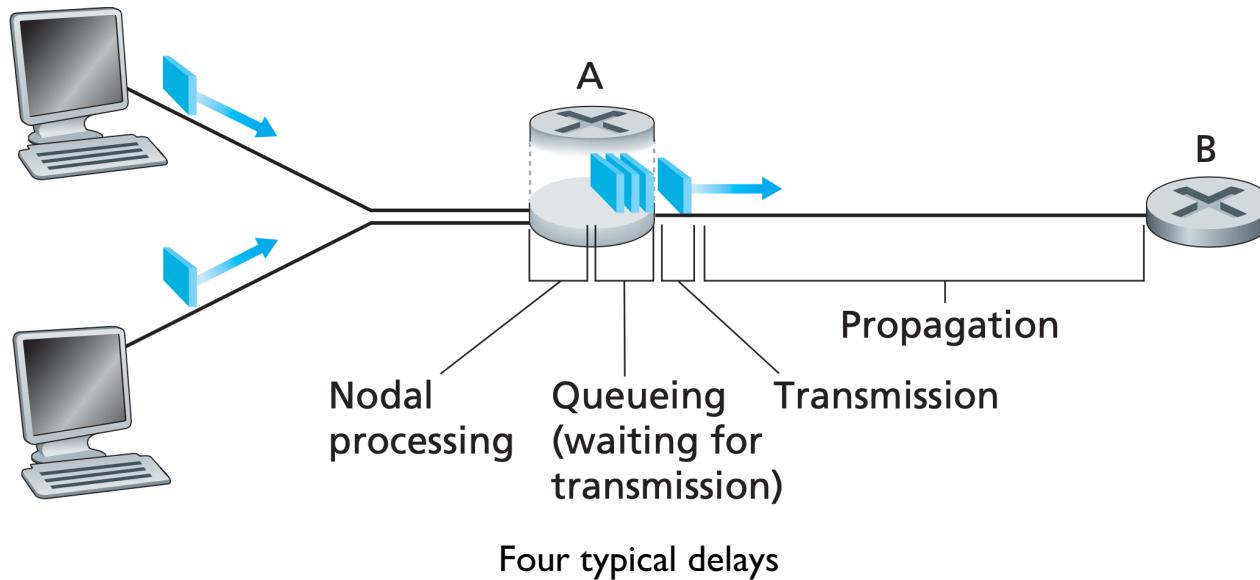
# A Network of Networks

- A customer-provider relationship at each level of the hierarchy
- Besides network structure (NS) 1~3 (Tier-1 ISPs, regional ISPs, access ISPs), the Internet also has points of presence (PoPs), multi-homing, peering, and Internet exchange points (IXPs) as NS4
- NS5 builds on top of NS4 by adding content provider networks
- “peer”



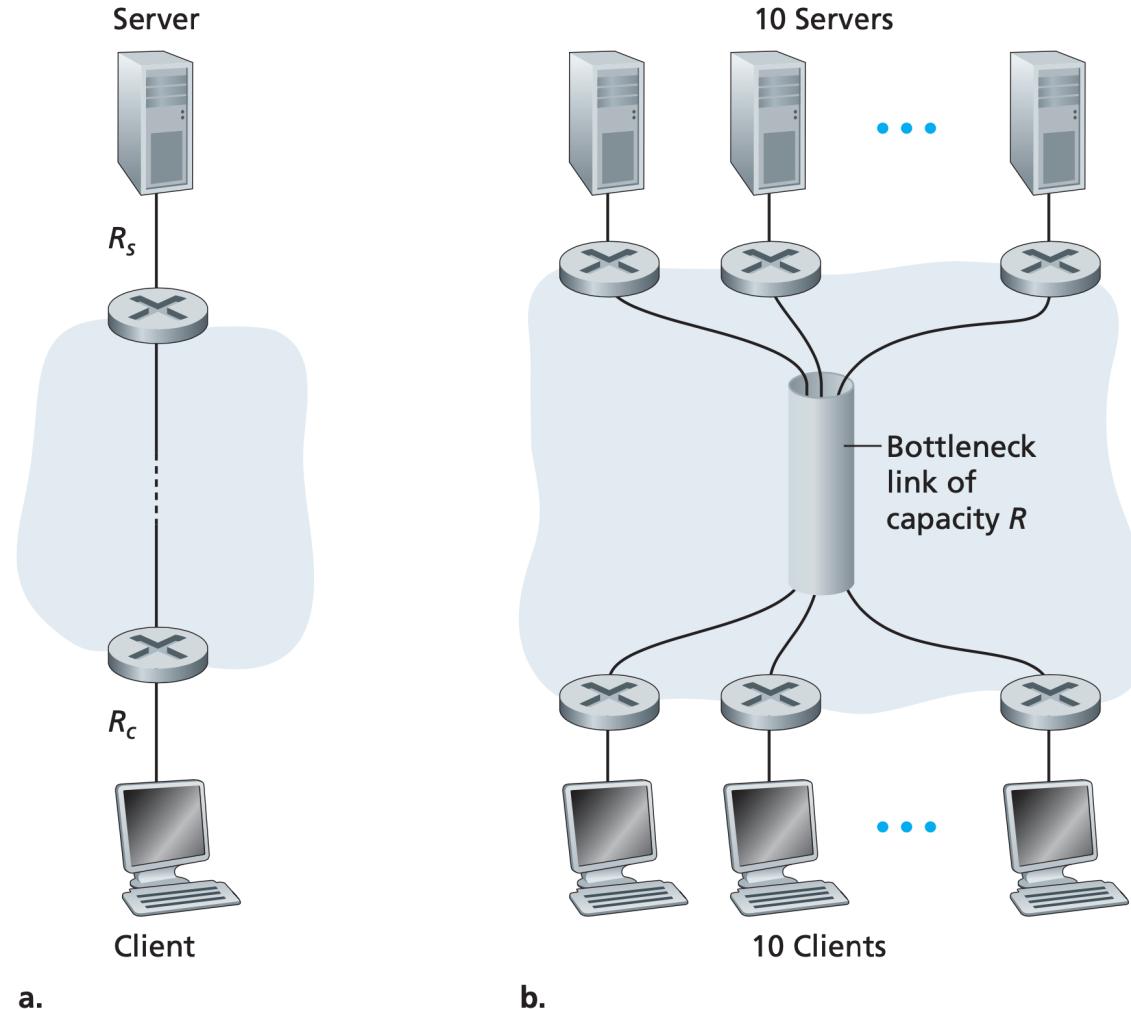
# Overview of Delay

- Nodal delay is the sum of four delays



# Throughputs

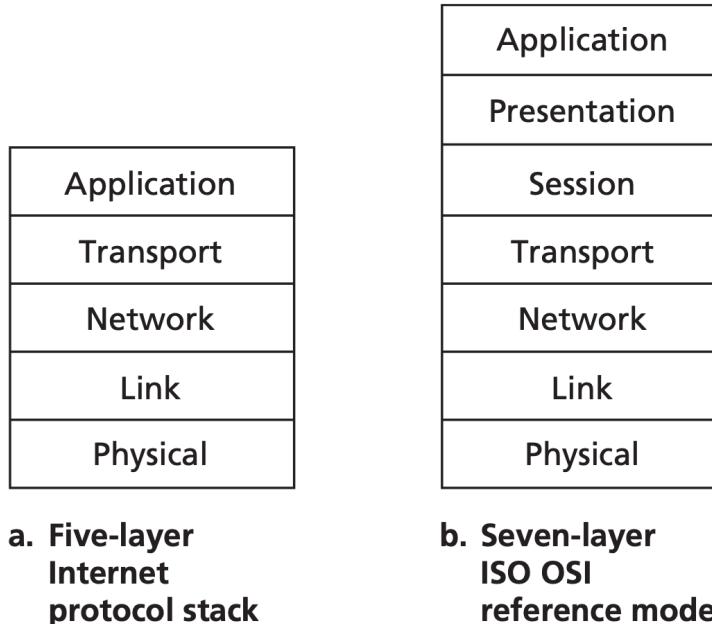
- Bottleneck link limits the actual throughput



End-to-end throughput: (a) Client downloads a file from server; (b) 10 clients downloading with 10 servers

# Protocols Layers and their Service Models

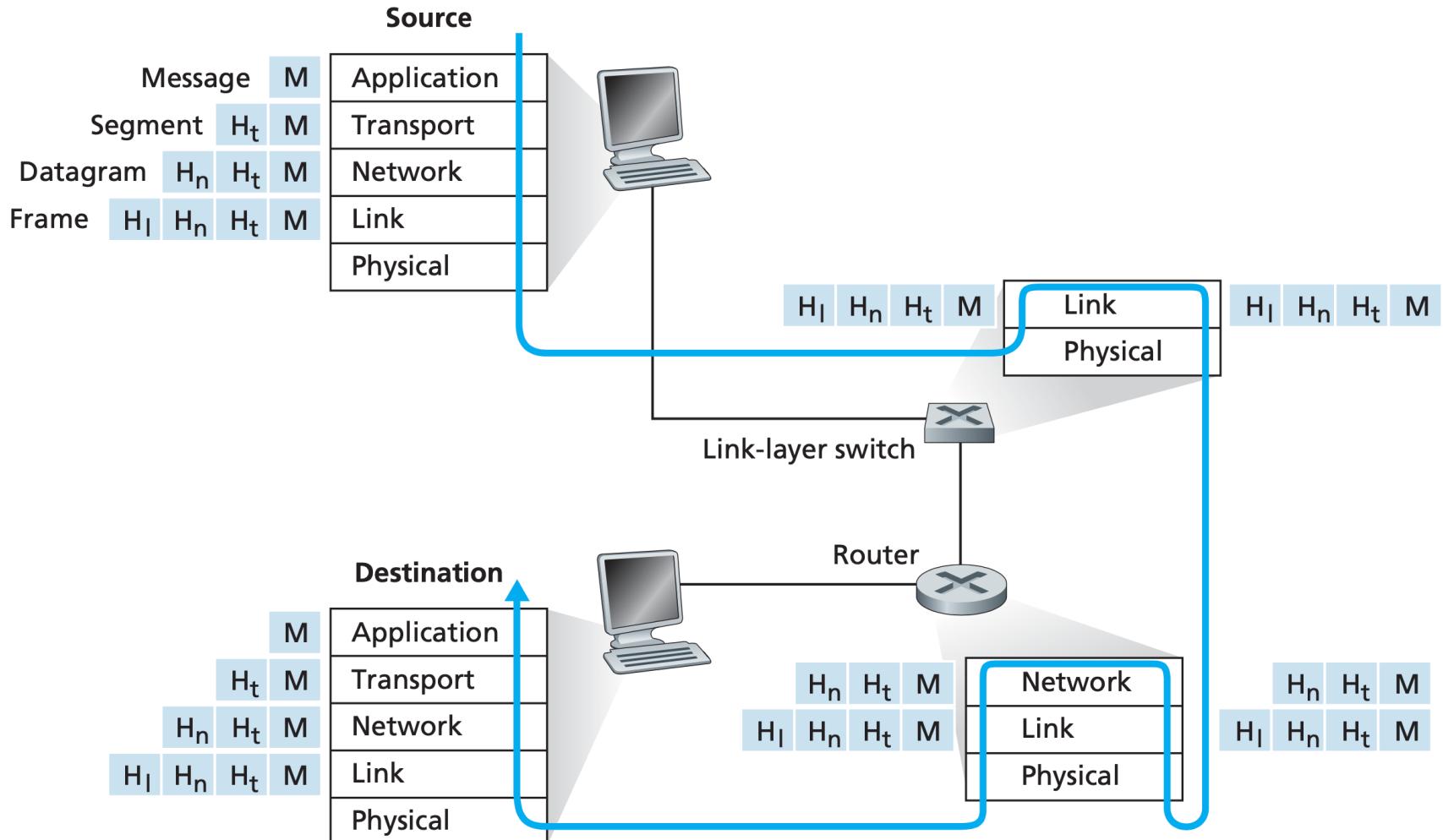
- Network designers organize protocols — and the network hardware and software that implement the protocols — in layers
- Each layer provides its service by (1) performing certain actions within that layer and by (2) using the services of the layer directly below it
- A protocol layer can be implemented in software, in hardware, or in a combination of the two



# Protocols Layers and their Service Models

- Application Layer - *message*
  - HTTP protocol (provides for Web document request and transfer)
  - SMTP (provides for the transfer of e-mail messages)
  - FTP (provides for the transfer of files between two end systems)
  - DNS (translation of human-friendly names for Internet end systems to a 32-bit network address)
- Transport Layer - *segment*
  - TCP (provides a connection-oriented service to its applications)
    - guaranteed delivery
    - flow control (i.e. speed matching)
  - UDP (provides a connectionless service to its applications)
- Network Layer - *datagrams* - host/router to host/router
  - IP protocol (defines the fields in the datagram as well as how the end systems and routers act on these fields)
  - routing protocols
- Link Layer - *frames* – link switch to link switch
  - Ethernet, WiFi, and the cable access network's DOCSIS protocol
- Physical Layer
  - move the individual bits within the frame from one node to the next
  - link dependent and further depend on the actual transmission medium of the link

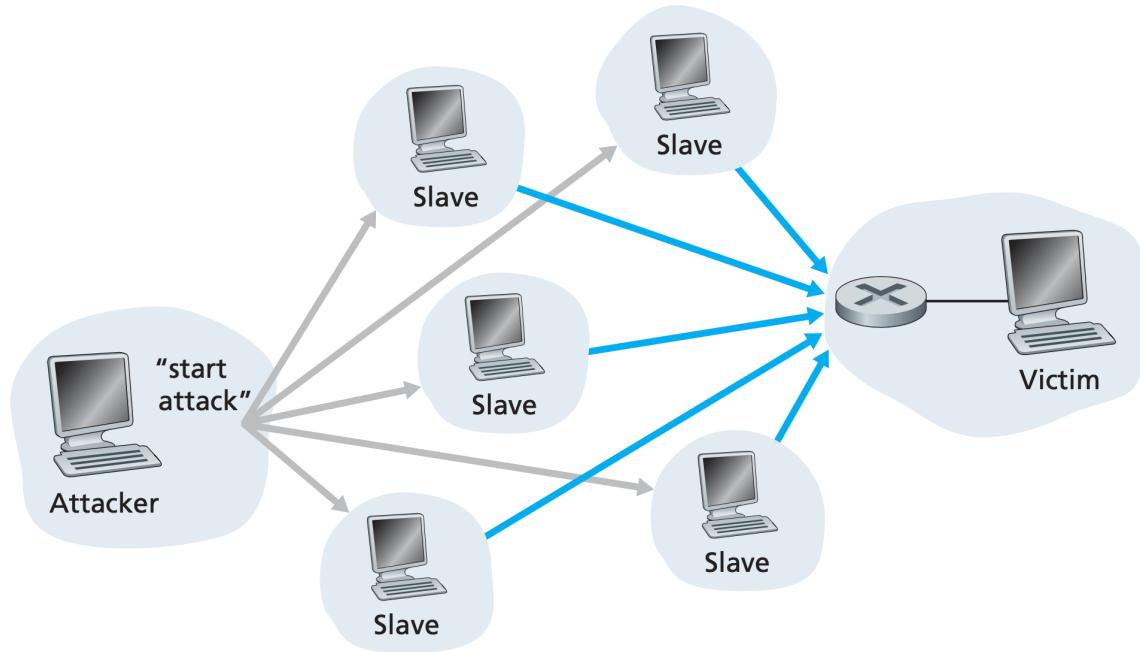
# Encapsulation



Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality

# Networks under Attack

- The DoS attack renders a network, host, or other piece of infrastructure unusable by legitimate users
  - Vulnerability attack
  - Bandwidth flooding
  - Connection flooding
- Virus, worms
- IP spoofing
- ...



A distributed denial-of-service attack