Principles of Modern Communications
Basic Concepts

Lecture series based on that of Dr. S. Waharte

Department of Computer Science and Technology
University of Bedfordshire

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Outline

Teaching Schedule

Introduction
Schedule for today

- Today, we are surrounded by networks.
- This lecture introduces basic network concepts and issues.
- It has a historical context because some aspects of networking only make sense if you understand the development of internetworking.

Introduction
Course Outline

Lecture #01 Basic Concepts

Lecture #02 Standards

Lecture #03 Physical Layer Propagation

Lecture #04 Digital Communications

Lecture #05 Amplitude/Frequency modulation

Lecture #06 Data communications

Lecture #07 Switched Data Networks

Lecture #08

Lecture #09 Wireless Networking

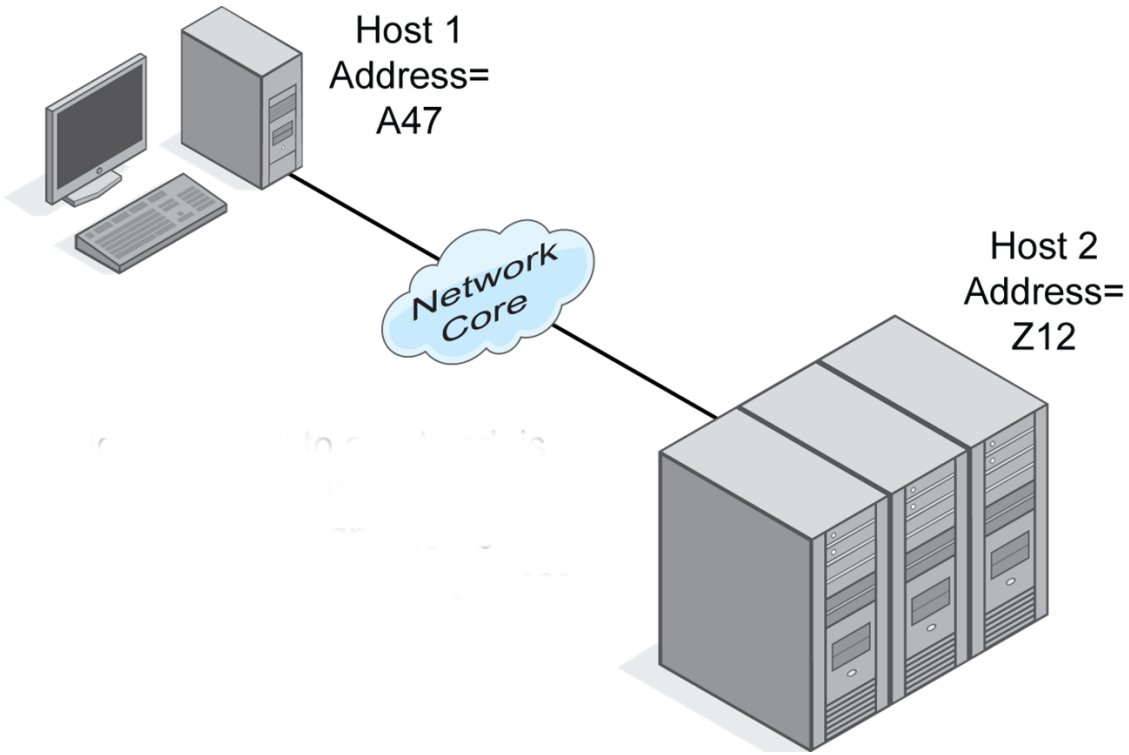
Lecture #10 Internetworks

Lecture #11 Networked Applications

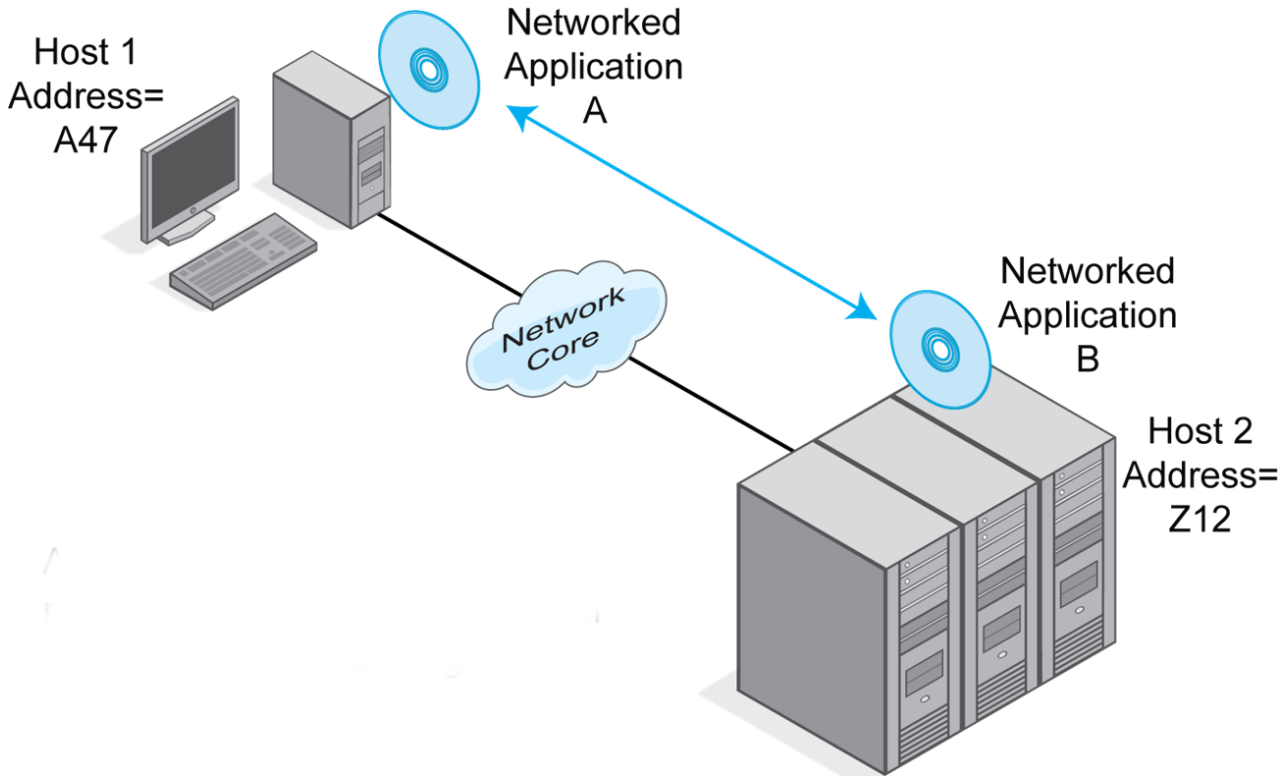
Lecture #12

Basic Network Terminology

Host
Basic Network Terminology



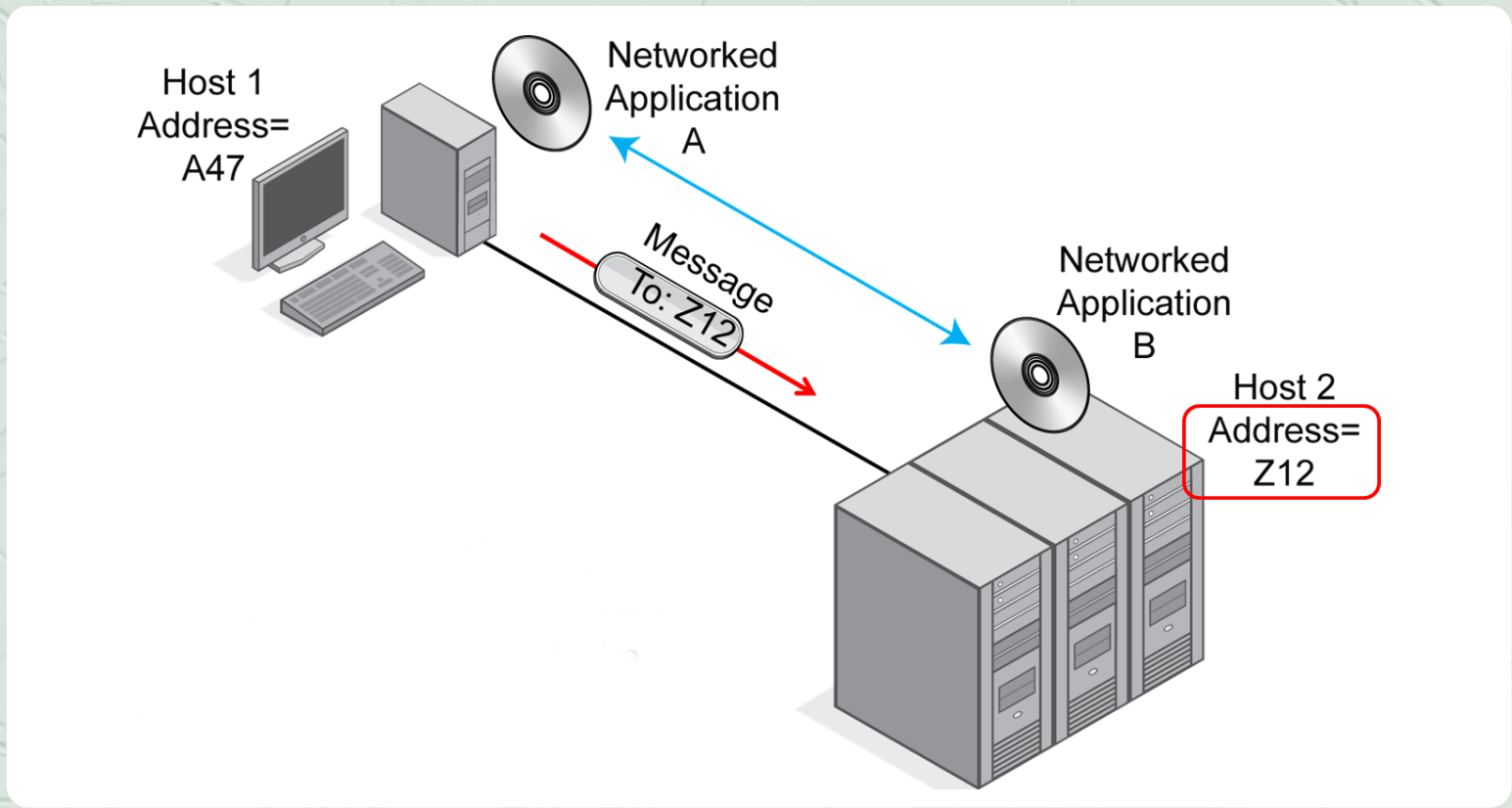
- Any device attached to a network is a host
  - Devices may include, but not be limited to, large servers, small desktops, laptops, netbooks, PCs, and smartphones.



- A network is a system that permits networked applications running on different hosts to work together.
  - Applications are the only things users care about.

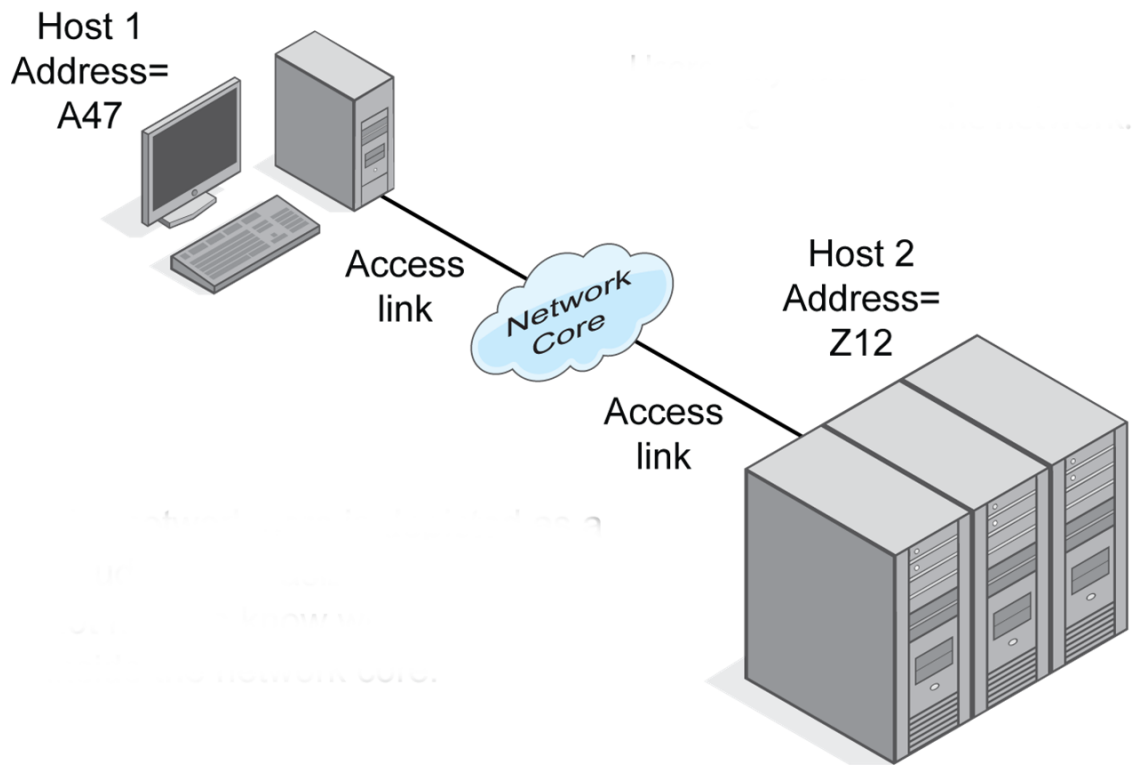
Networked Applications

- Applications that require a network to function
- 1970s
  - E-mail, file downloading, and transfers
- 1990s
  - The Wide Web, instant messaging
- This century
  - Web 2.0 with user-developed content, e.g., Wikipedia, YouTube
  - Social networking, e.g., Facebook
  - Streaming media



- Applications communicate by sending messages to one another.
- Messages are addressed to the receiver's address.

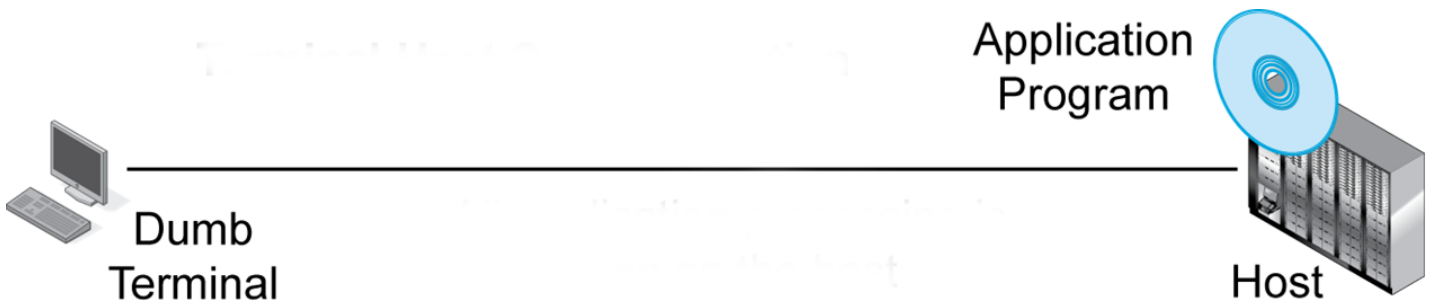
Access Links
Basic Network Terminology



- Users may have to know about their access links to the network.
  - The network core is shown as a cloud to emphasize that users do not have to know what goes on inside the network core.

Terminal-Host Communication

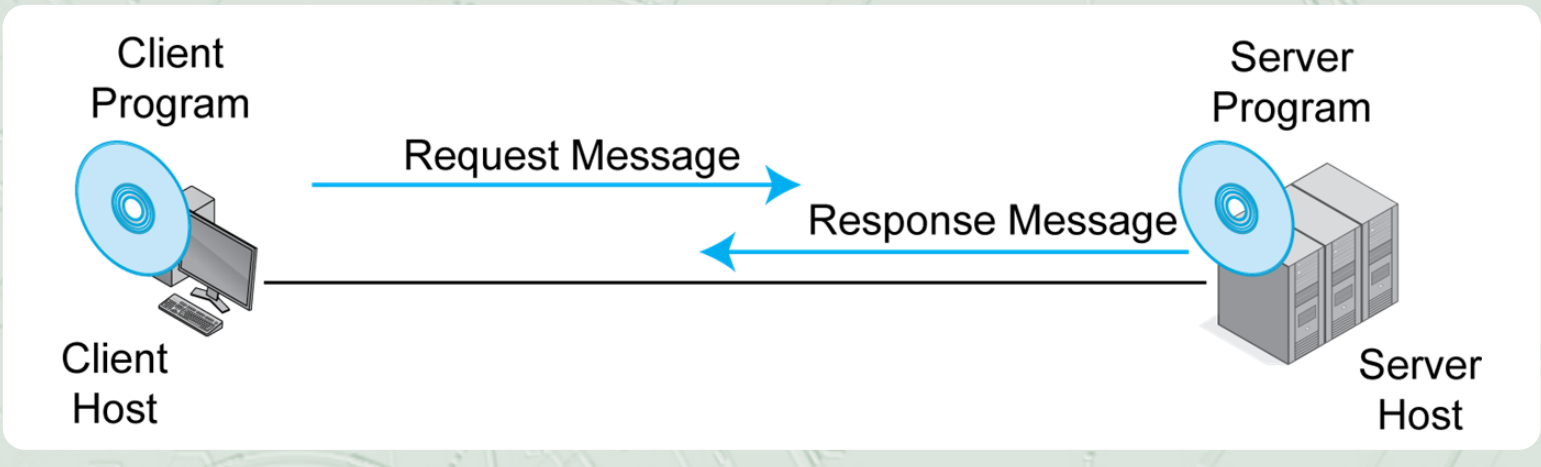
Terminal-Host v Client/Server



- All application processing is done on the host.

Client/Server Processing

Terminal-Host v Client/Server



- The client and server hosts share the application processing work.
  - Made possible by the emergence of PCs

Beyond Client/Server Computing

- Peer-to-Peer (P2P) Computing
  - Clients provide service to each other.
  - Made possible by growing PC processing power.
- Cloud Computing
  - Resources are outsourced to a provider who is accessed entirely via a network.
  - Users only need a PC or other intelligent device.
  - Company does not need to maintain servers or applications.

Transmission Speed

Transmission Speed Measurements		
Normally measured in bits per second (bps)		
Usually not in bytes in per second (Bps)		
Metric Prefixes		
Kilobits per second	kbps (lower-case k)	1,000 bps (not 1,024)
Megabits per second	Mbps	1,000,000 bps
Gigabits per second	Gbps	1,000,000,000 bps
Terabits per second	Tbps	1,000,000,000,000 bps

Transmission Speed

Metric Prefixes

- Examples of Metric Prefixes (k, M, G)
  - 56,000 bps is 56 kbps.
  - 45,370 bps is 45.37 kbps.
  - 34 Mbps is 34,000,000 bps.
  - 4,676 bps is 4.676 kbps.
  - 23,000,000 bps is 23 Mbps.

Download Time for Applications

The Need for Speed

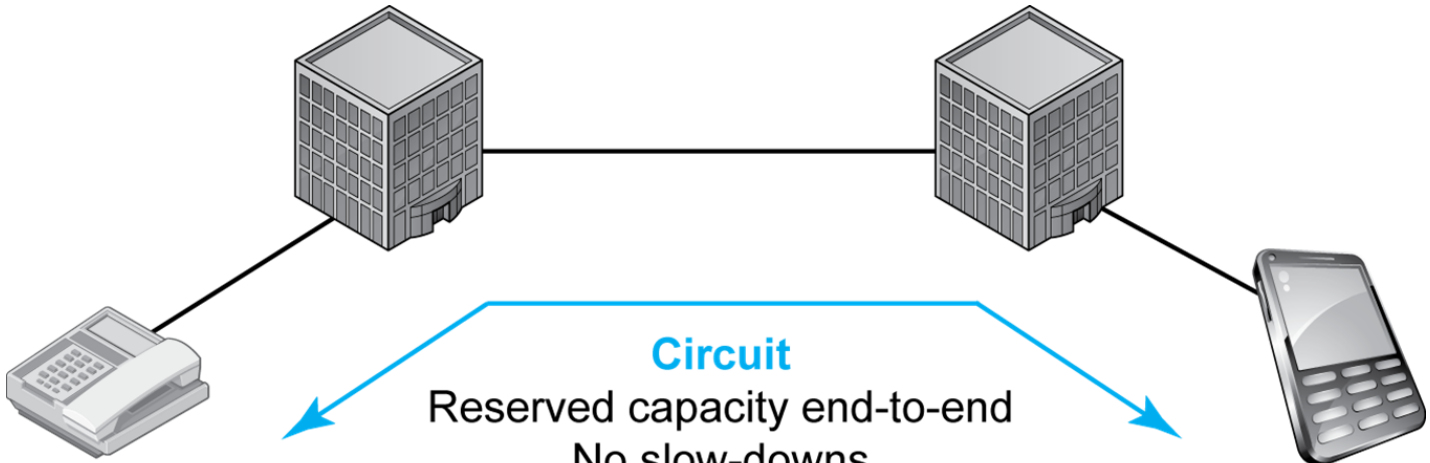
Application	100 kbps	1 Mbps	10 Mbps	100 Mbps
E-Mail (250 words)	0.02 sec	0 sec	0 sec	0 sec
Photo (2 MB)	2.7 min	16 sec	2 sec	0 sec
MP3 Song (3 min)	2.9 min	17 sec	2 sec	0 sec
Ltd. Quality TV (One Hour)	13 hrs	1 hr	8 min	1 min

Circuit Switching

Circuit Switching

- Circuit-switched transmission systems give reserved capacity to users

Telephone Circuits



- Circuits give you reserved capacity to the other party for the duration of the call
  - On every switch along the way
  - On every line along the way

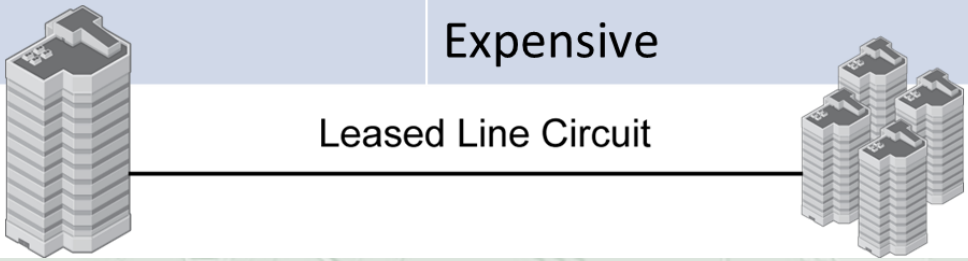
Questions About Circuits

Example (1)

1. How does the telephone system handle circuit switching reserved capacity on Mother's Day, when there is excess traffic?
2. Why is this not necessary on Father's Day?

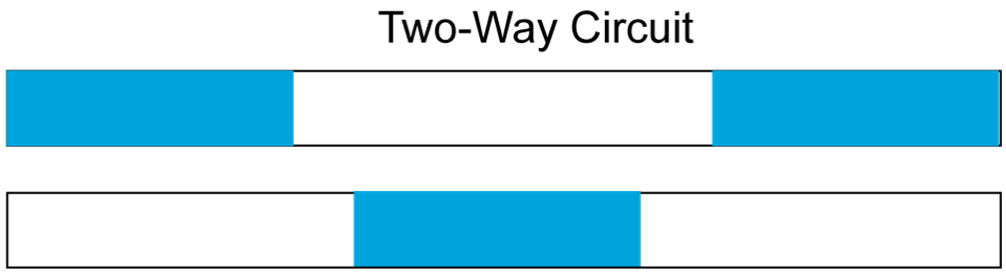
Telephone Circuits

Dial-Up Circuit	Leased Line Circuit
For homes and businesses	For businesses
Can call anyone	Point-to-point connection between two sites
Reserved capacity for duration of a call	Always on with reserved capacity
Low speeds for data (30 to 60 kbps)	Speeds of megabits or gigabits per second
Inexpensive	Expensive

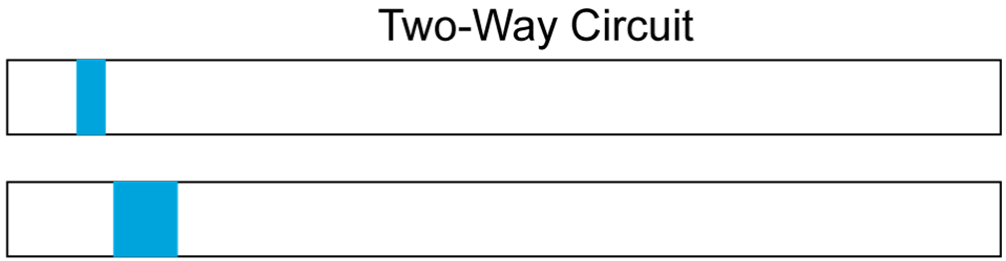


Data Burstiness and Reserved Circuit Capacity

Voice Traffic:
Fairly constant use.
Circuit switching is fairly efficient



Data Traffic:
Short bursts,
Long silences;
Circuit switching is very inefficient



- Circuit switching's guaranteed capacity is economical for voice, but not for bursty data.

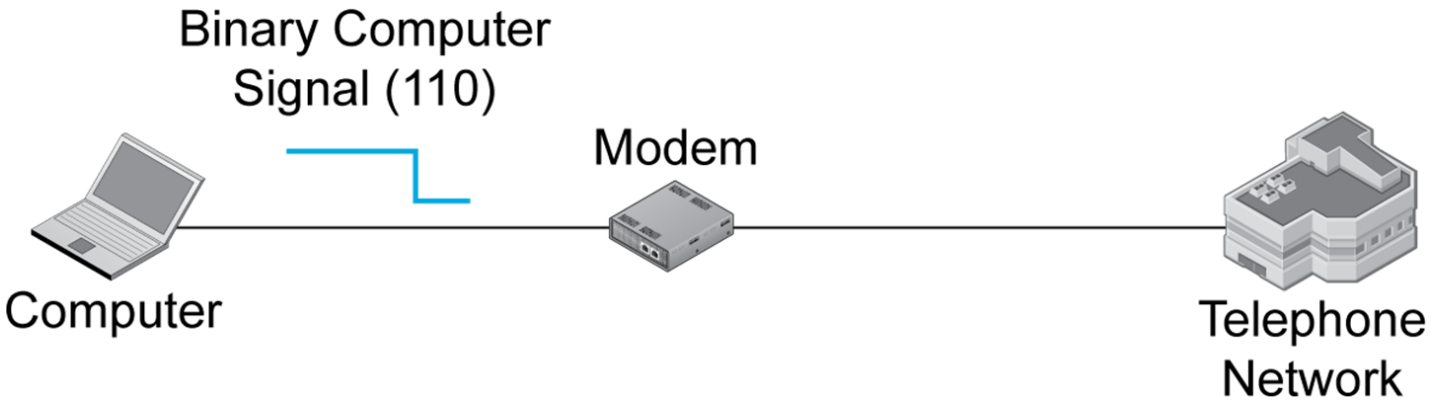
Telephone Modems

Analog, Binary, and Digital Transmission

- When you speak, your telephone handset produces an analogous (analog) electrical signal.
  - If you talk louder, the signal gets stronger.
- The telephone network expects you to send analog signals.

Telephone Modems

Analog, Binary, and Digital Transmission



- Your computer transmits digital signals
- Digital signals change abruptly between states (voltages etc.)
- If there are two states, this is binary transmission
  - One state is 1, the other state is 0.
- If there are several states (more than two), then this is digital transmission.

Telephone Modems

- Binary
  - 2 states
- Digital
  - A few states
  - 2, 4, 8, 16, 32,. . .

Example (2)

1. If transmission is binary, is it also digital? Explain.
2. If transmission is digital, is it also binary? Explain.

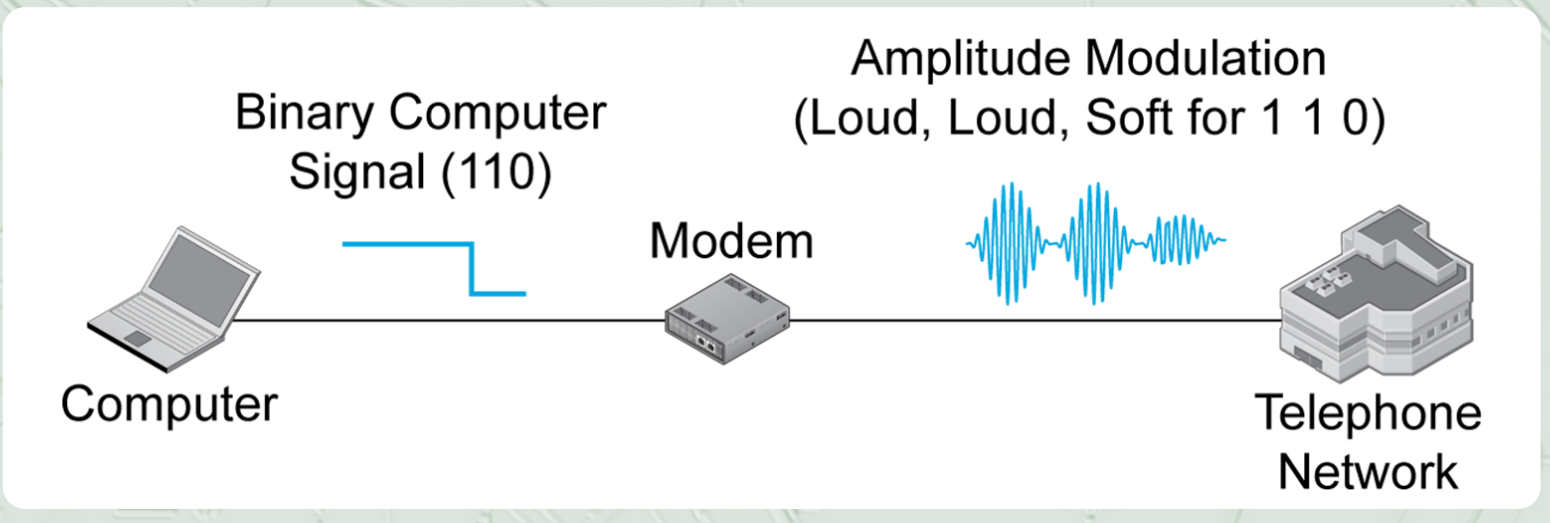
Binary versus Digital Questions

Example (3)

1. If you have 2 states, is this . . .
   a. Binary?
   b. Digital?
   c. Analog?
2. If you have 8 states, is this . . .
   a. Binary?
   b. Digital?
   c. Analog?

Telephone Modems

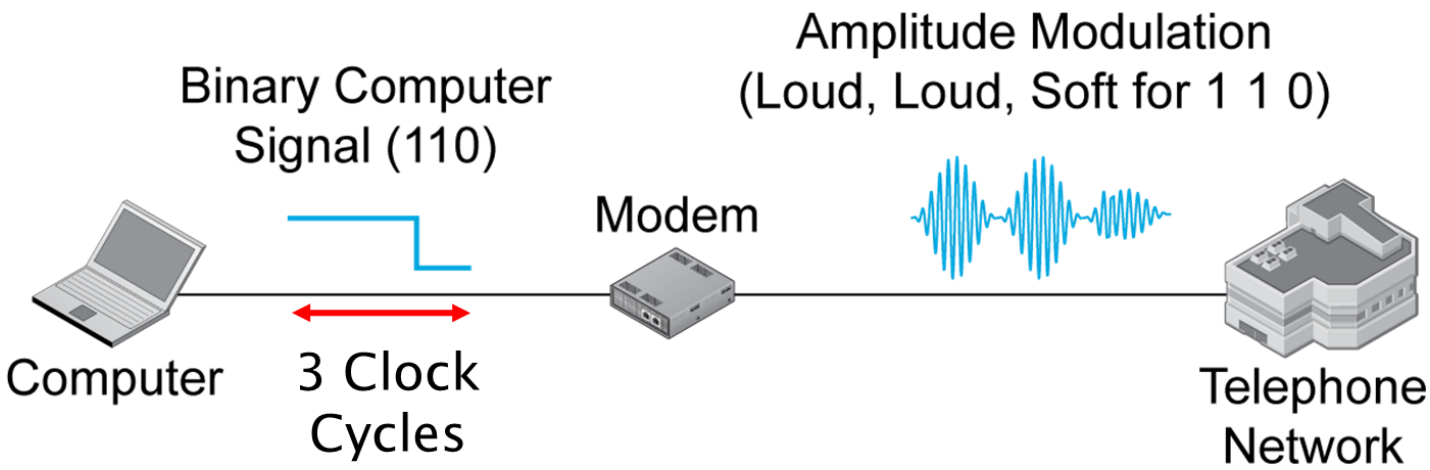
Analog, Binary, and Digital Transmission



- The telephone network expects analog signals.
- A modem converts digital computer signals into analog transmission signals.
- Here, 1, 1, 0 is converted into loud, loud, soft.
- This is amplitude modulation.

Telephone Modems

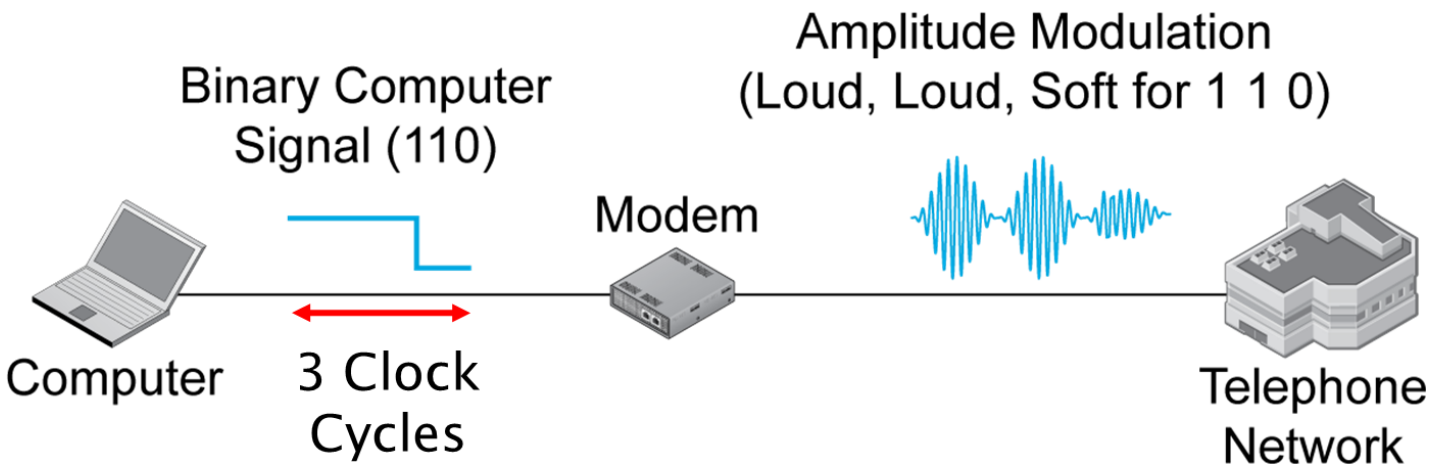
Analog, Binary, and Digital Transmission



- In digital signals, the signal is held constant in each clock cycle.
- At the end of a clock cycle, it can change or stay the same.

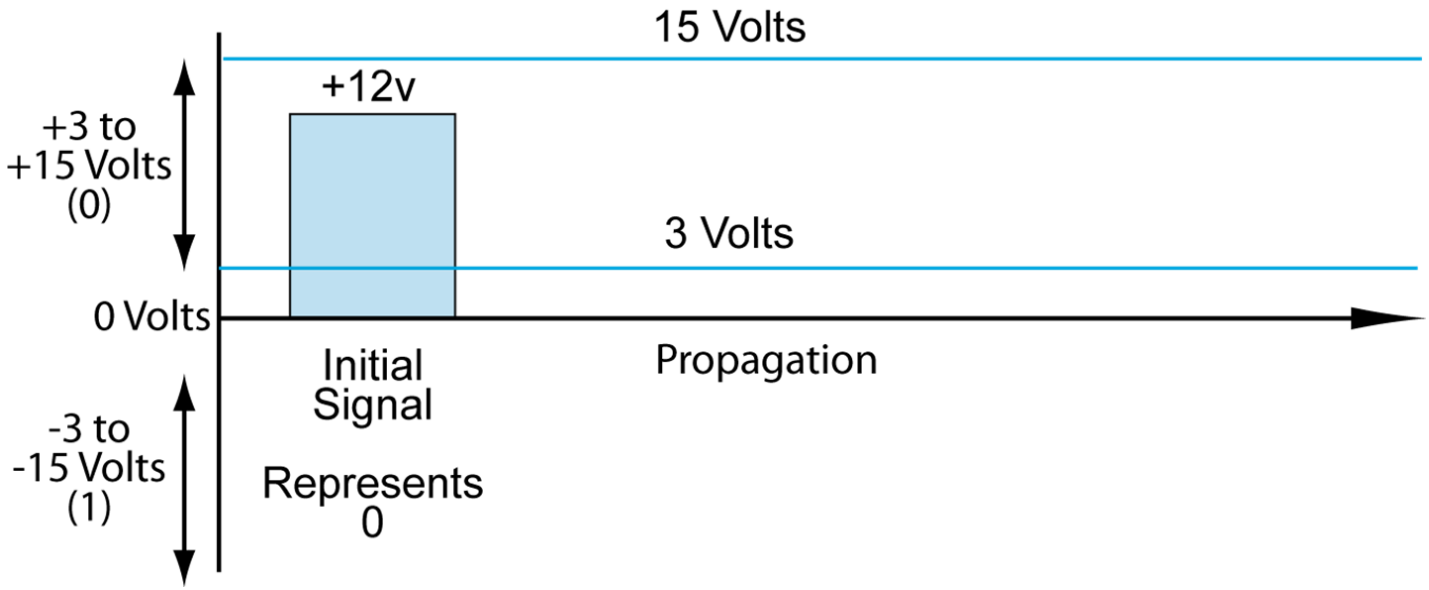
Telephone Modems

Analog, Binary, and Digital Transmission



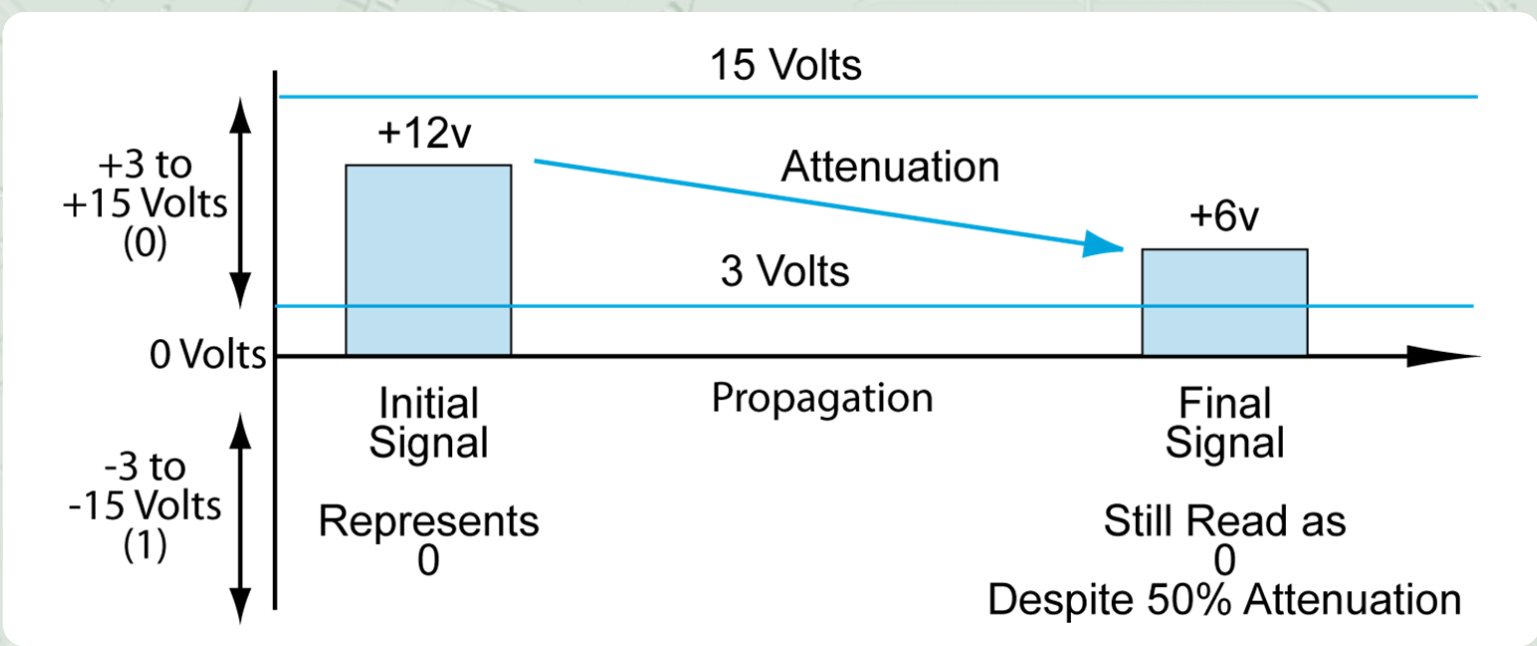
- Here, the first two bits are 1s. There is no change.
- Clock cycles allow the modem to know that it is two 1s, rather than a single long 1.

Resistance to Errors in Digital Signaling



- An example of binary signaling.
- 12 volts during a clock cycle is a 0.
- +3 to +15 volts is a 0.
- This is only an example. Other systems will represent 0s and 1s differently.

Resistance to Errors in Digital Signaling



- Even if there is attenuation, the signal probably will be read correctly.

Resistance to Errors in Digital Signaling

Number of states	Bits sent per clock cycle	Representation of states
2 (binary)	1	State 1=0, State 2=1
4	2	Four states can represent 00, 01, 10, and 11
8	3	Eight states can represent 000, 001, 010, 011, 100, 101, 110, 111

- Having more than two states allows you to send multiple bits per clock cycle.

Resistance to Errors in Digital Signaling

Number of states	Bits sent per clock cycle	Representation of states
2 (binary)	1	State 1=0, State 2=1
4	2	Four states can represent 00, 01, 10, and 11
8	3	Eight states can represent 000, 001, 010, 011, 100, 101, 110, 111

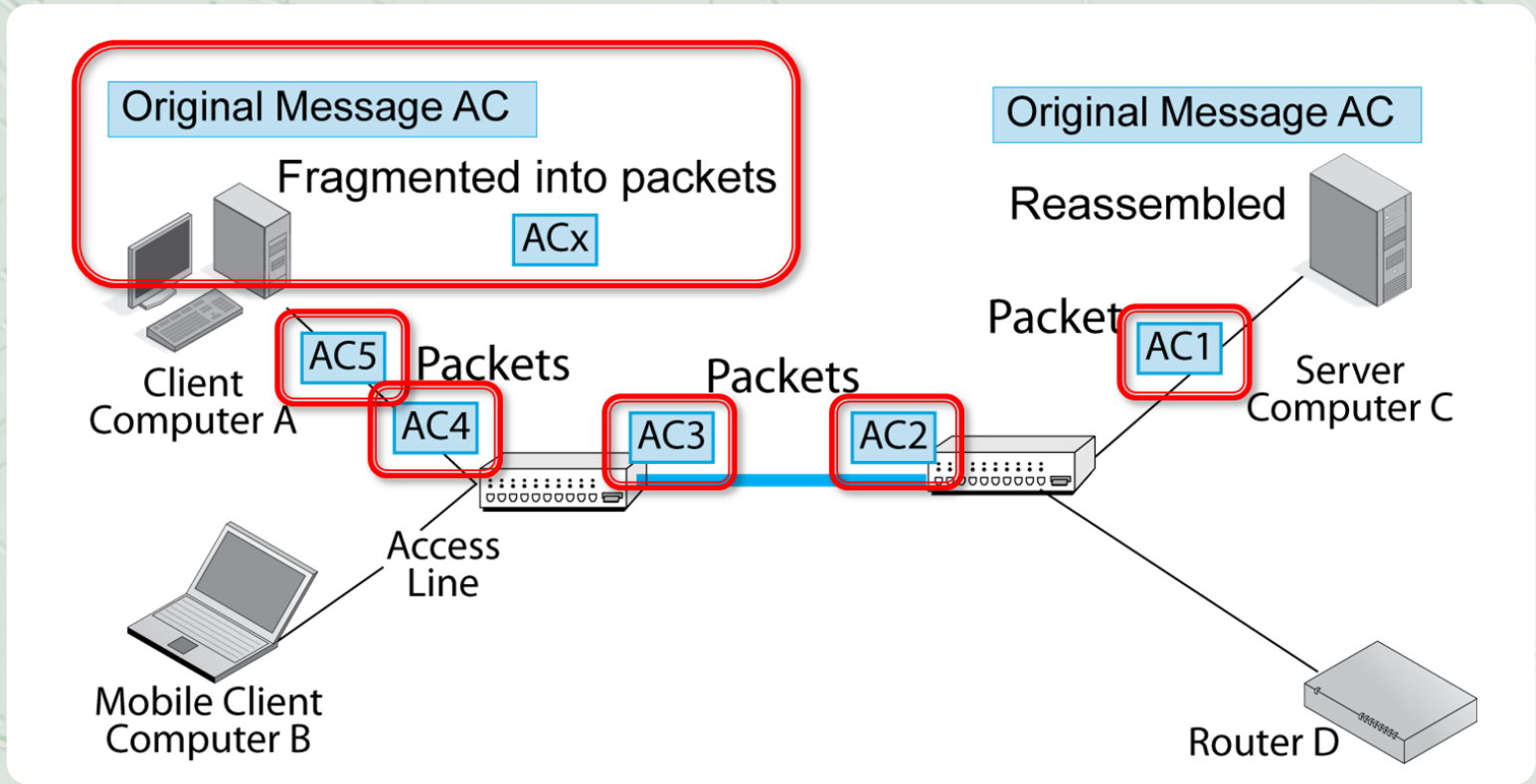
- However, the voltage and other differences between the states become smaller, so there are more errors.

The Need for Packet Switching

Packet Switching

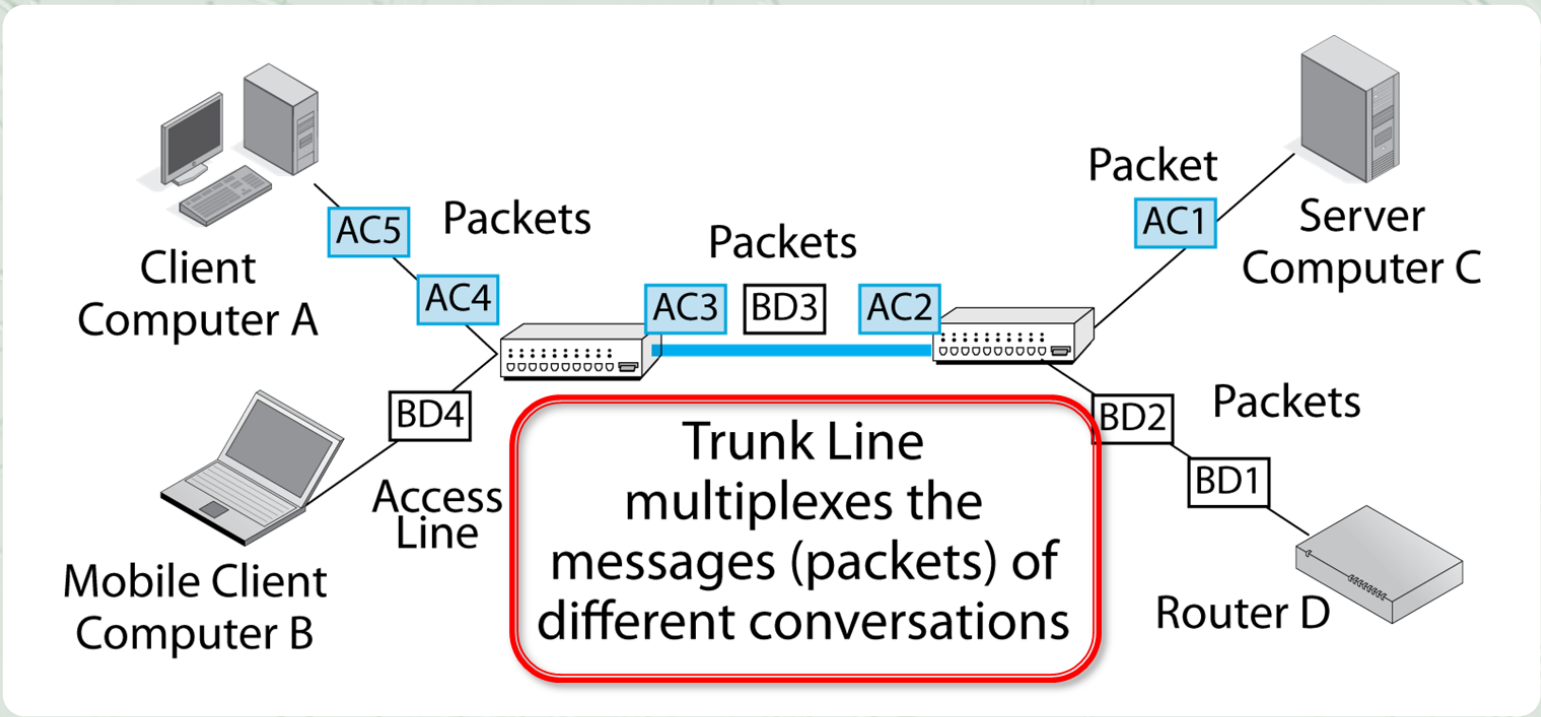
- We have seen that circuit switching's reserved capacity is reasonably efficient for voice conversations, in which someone is almost always talking.
- But circuit switching's reserved capacity is inefficient (and therefore expensive) for data transmissions, in which there are high-speed bursts separated by long silences in which expensive reserved capacity goes unused.
- Packet switching is a more efficient way to send data.

Packet Switching and Multiplexing



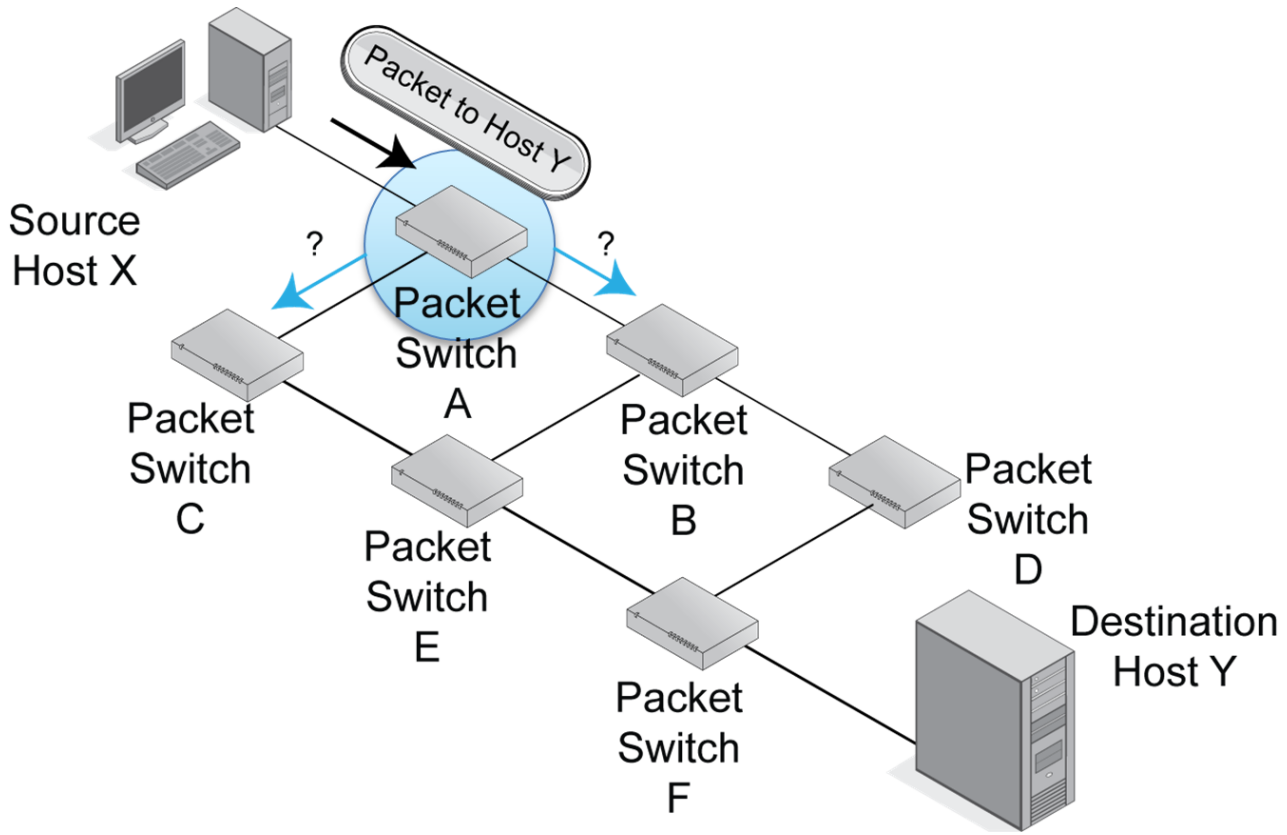
- Packet Switching:
  - Original message is fragmented, then sent in many packets.
  - Reassembled by the receiver.

Packet Switching and Multiplexing



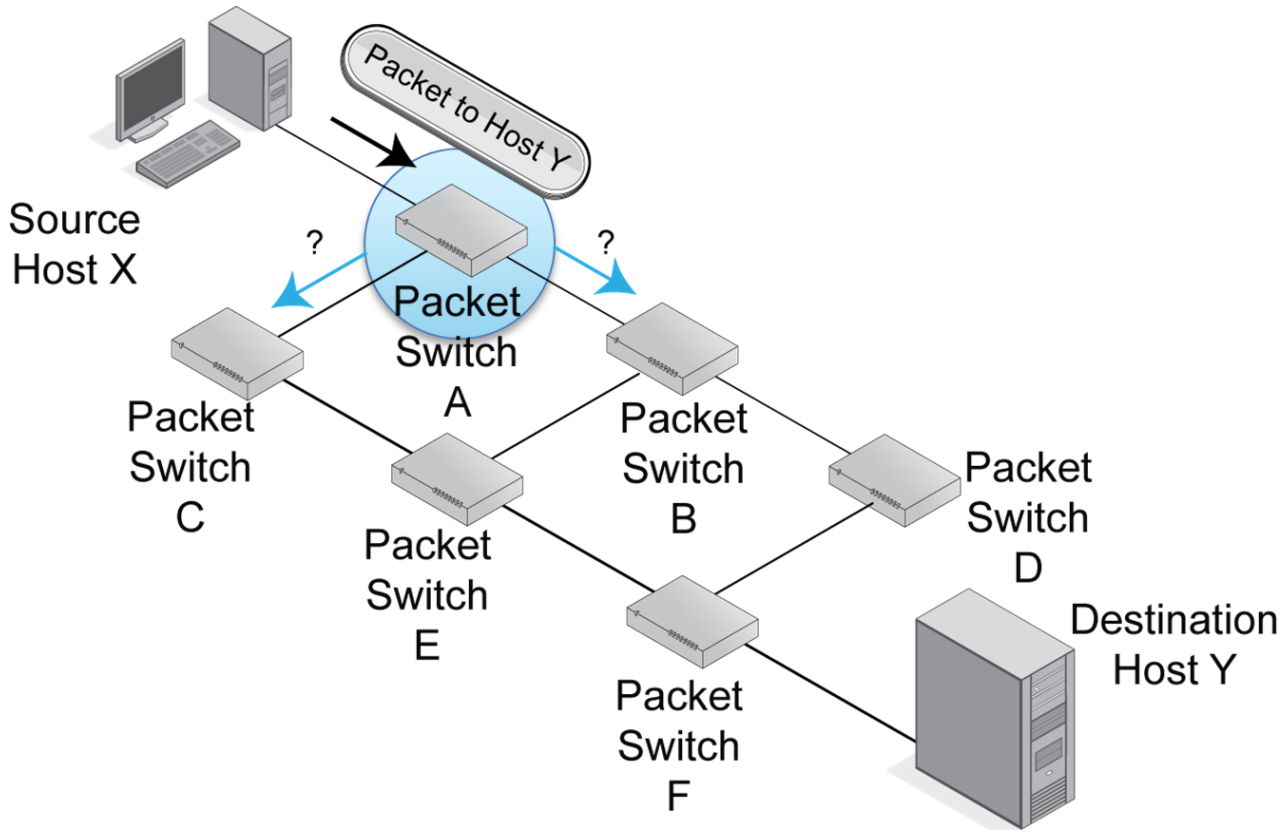
- Packets of different conversations share the cost of trunk lines between packet switches.
- This makes packet switching inexpensive compared to circuit switching.

Sequential Switch Forwarding Decisions



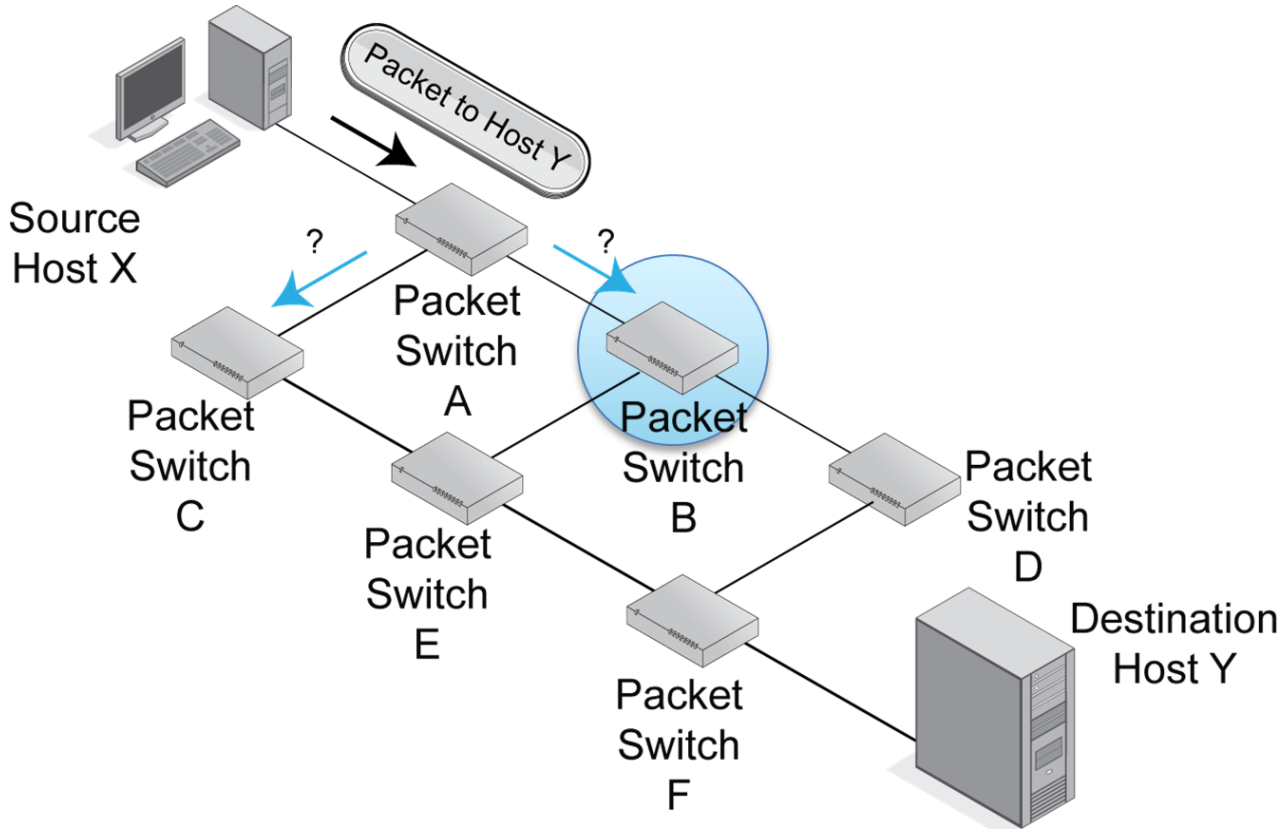
- Packet Switch A receives packet addressed to Host Y.
- Packet Switch A decides to send the packet to B or C.
- This is a forwarding decision.

Sequential Switch Forwarding Decisions



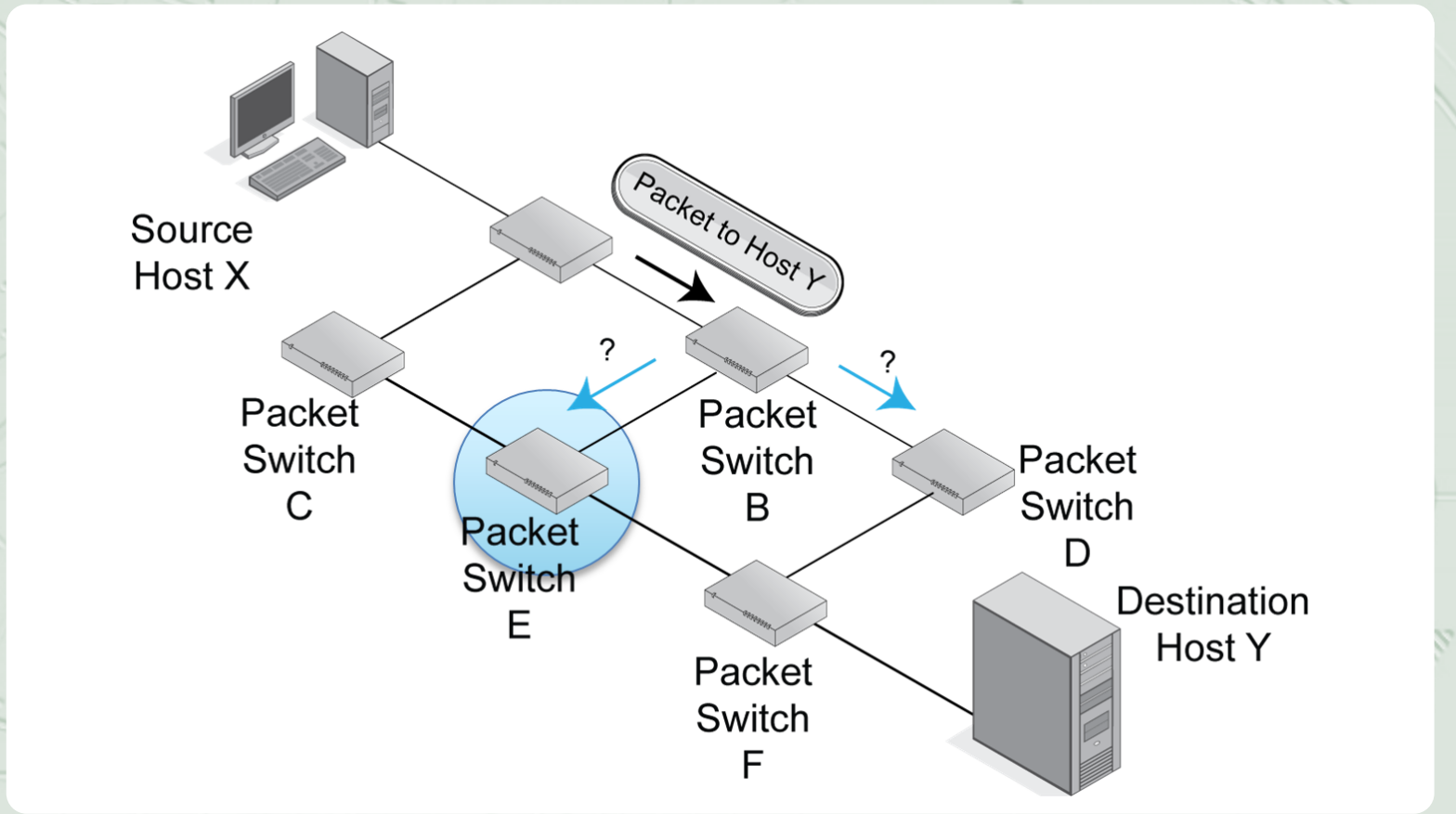
- The packet switch does not know the entire path.
- It only knows the next switch.

Sequential Switch Forwarding Decisions



- If Packet Switch A forwards the packet to Packet Switch B, what are Packet Switch B's choices?

Sequential Switch Forwarding Decisions



- Packet Switch B can forward the packet to D or E.
- If Packet Switch B forwards the packet to Packet Switch E, what are Packet Switch E's choices?

Recap

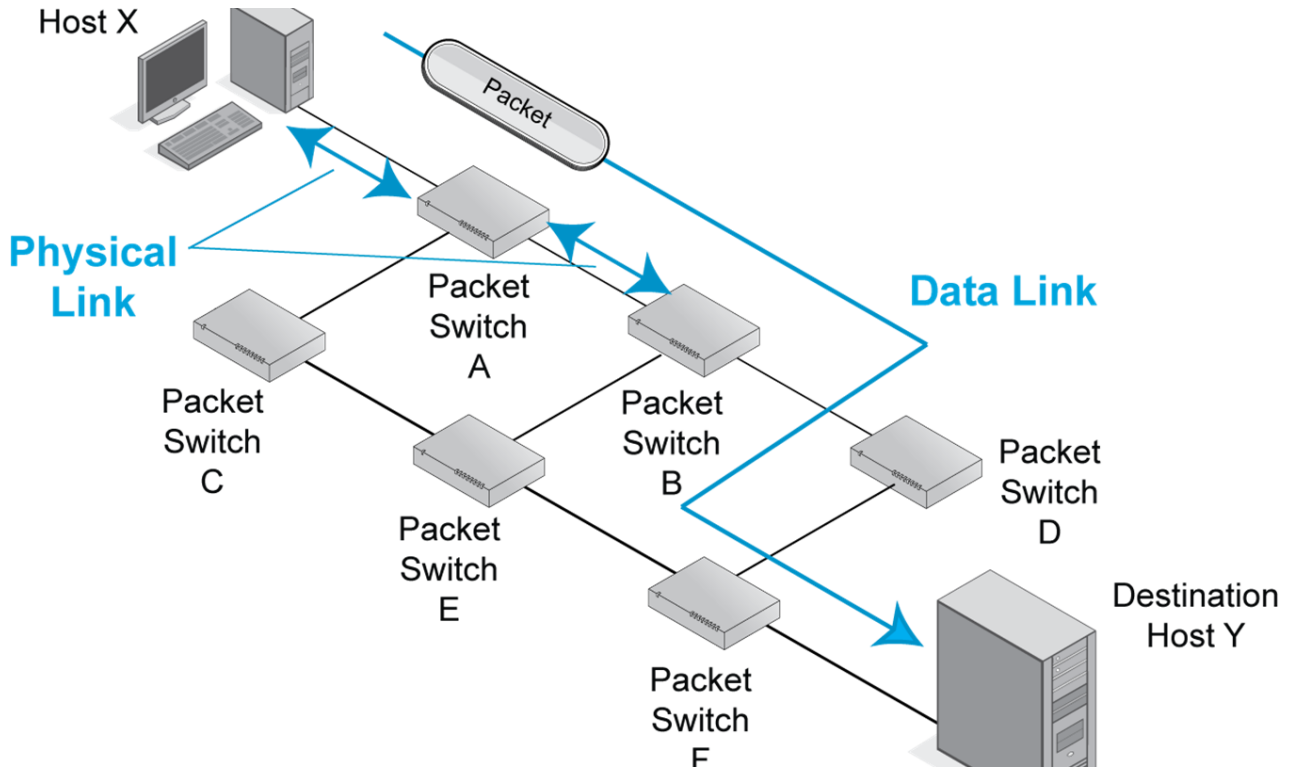
- Each switch along the way forwards the packet out a port to another switch (or to the destination host).
- Individual packet switches have no knowledge of the entire path taken by the packet.
- We will see how this works in detail in later chapters.

Network layers

Network layers

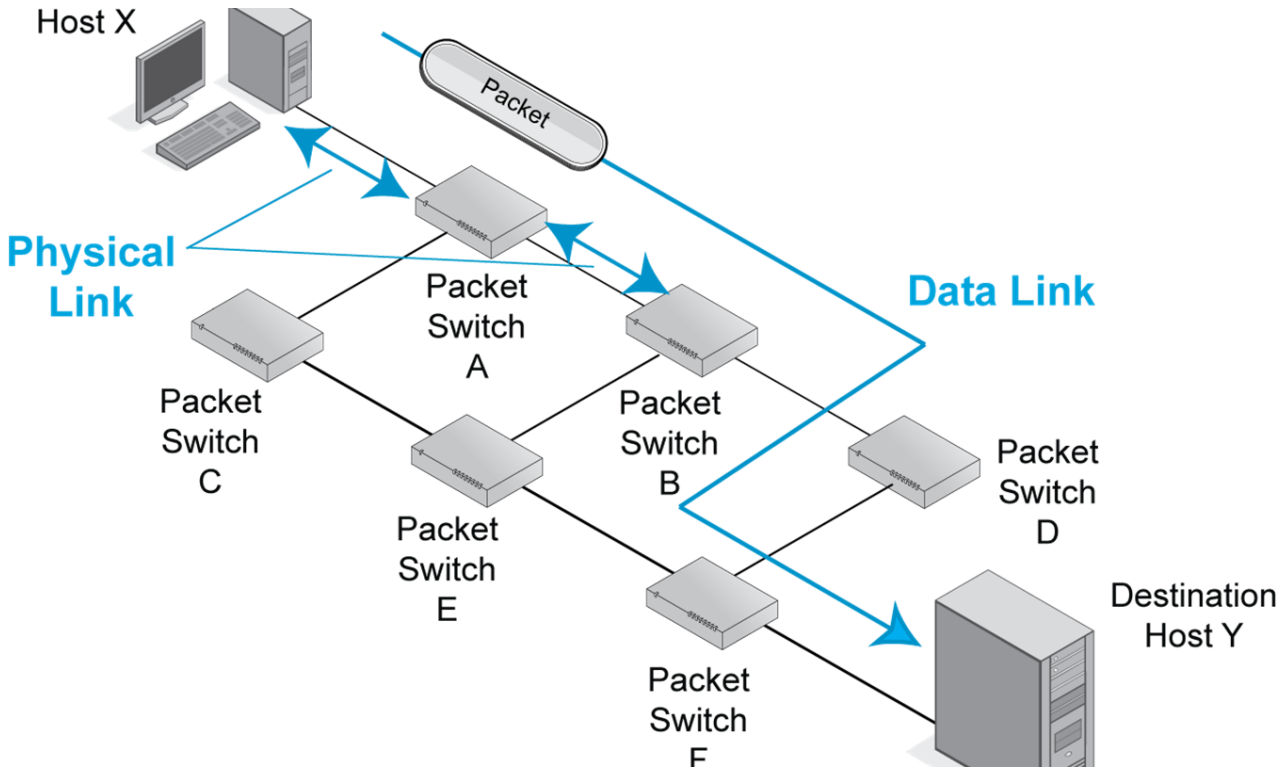
- Networks can be described at several layers of detail.
  - By analogy, humans can be described sociologically, psychologically, in terms of musculature, and at the cell level.
- Each layer provides services to the layer above it.
  - The road provides service to the car tires.
  - The car tires provide service to the car.
  - The car provides service to the driver.
  - A commercial driver provides service to the goods being delivered.

Physical Links and Data Links



1. Physical links are connections between adjacent pairs of devices.
2. The data link is the packet's path through the network. In this case: X-A-B-D-F-Y

Physical Links and Data Links



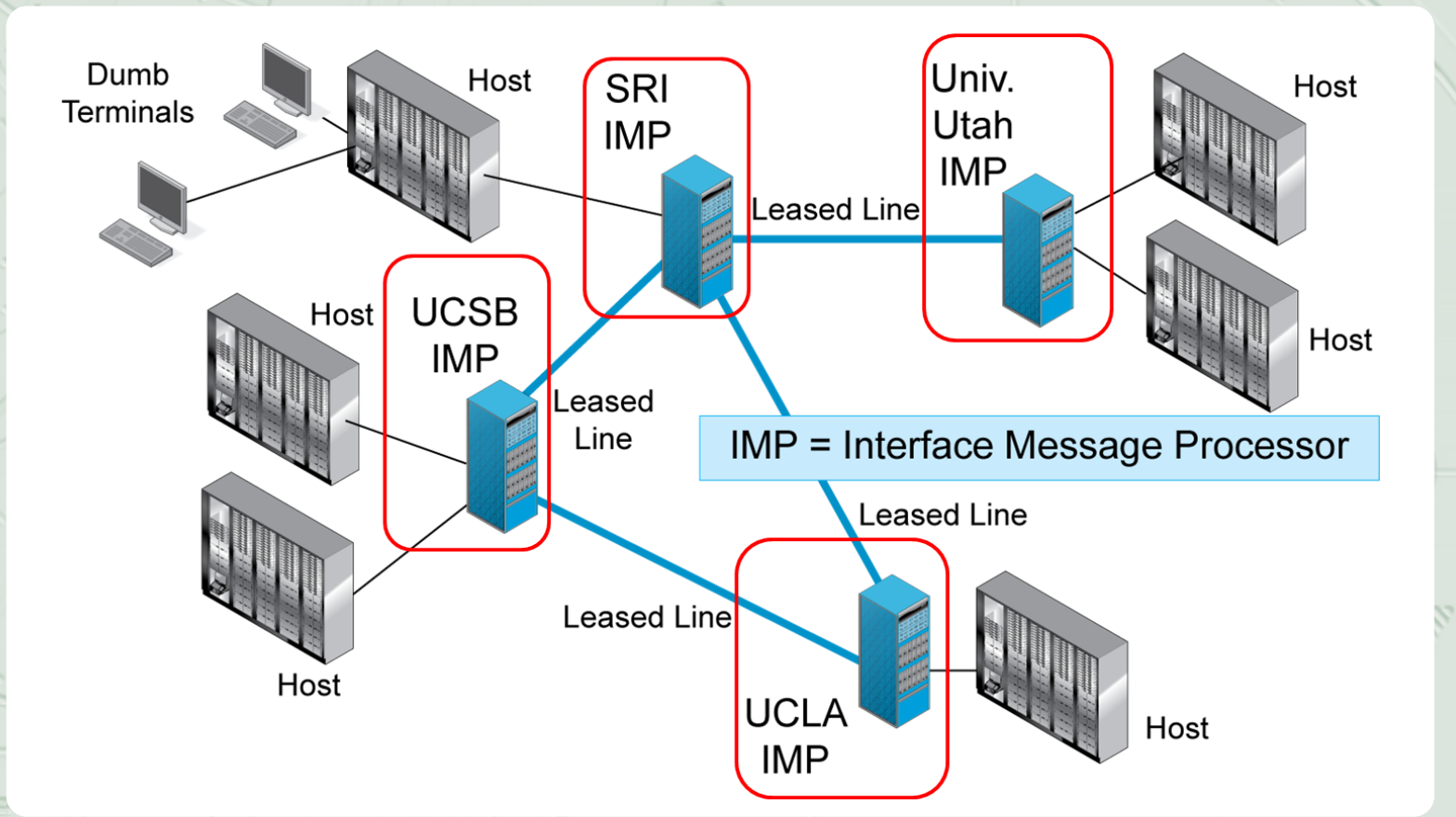
Example (4)

1. How many data links does the packet pass through?
2. How many physical links does the packet pass through?
3. Name them.

The ARPANET

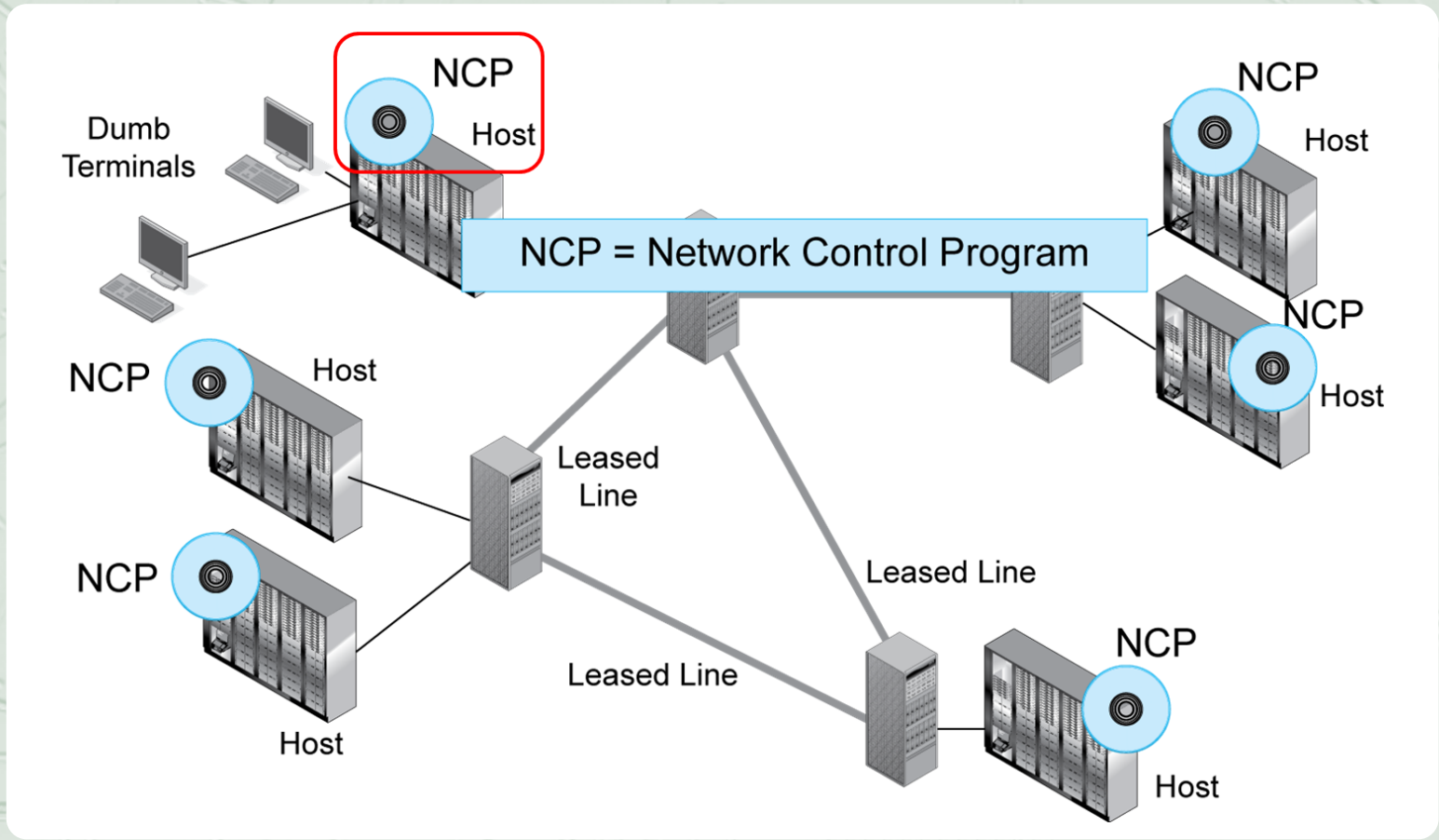
- Forerunner of the Internet
- Funded by Larry Roberts at the Advanced Research Projects Agency (ARPA)
  - Now the Defense Advanced Research Projects Agency (DARPA)
- To explore packet switching
- To give researchers access to ARPA-funded software on hosts computers in distant cities
- First four nodes began operation in 1969

The ARPANET (First 4 Nodes)



- Packet switches were called IMPs. Each IMP could serve multiple hosts at a site.

The ARPANET (First 4 Nodes)



- Each host ran the NCP software. The NCP coordinated the host's communication with its IMP.

Network Working Group

- Formed by graduate students to create standards for the ARPANET
- Called their standards Requests for Comment (RFCs)
  - Did not feel that they had the authority to create standards, so they used the weaker term RFC
- The NWG evolved into todays standards body for the Internet, the Internet Engineering Task Force (IETF)
- Internet standards today are still called RFCs

INTERNETS

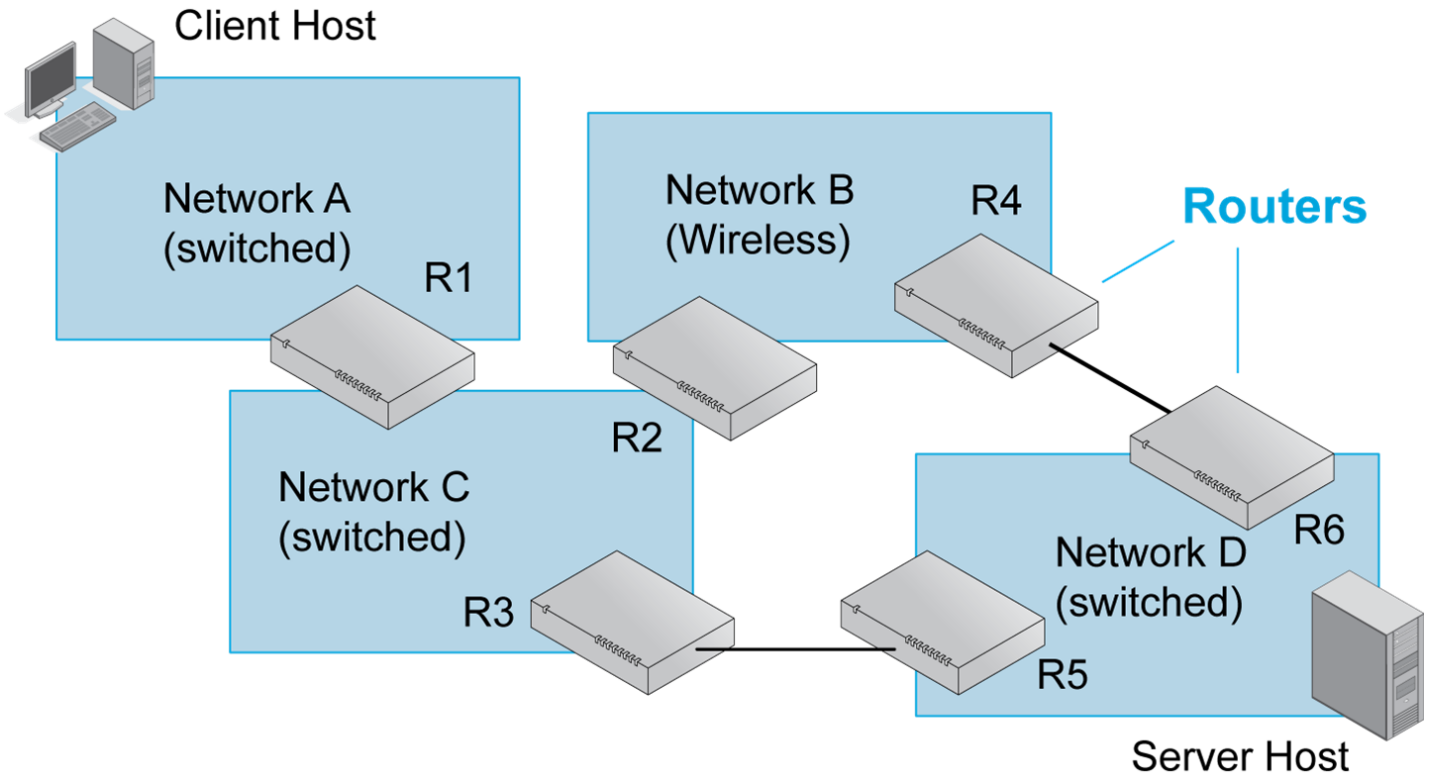
Birth of the Internet

- Bob Kahn at DARPA needed a way for researchers on one network to be able to use resources on another network.
- Packets would have to travel across multiple networks.
- Kahn and Vint Cerf came up with the idea of connecting multiple networks by devices called routers.
- (The original name was gateways.)
- Generically, networks of networks are internets.
- Kahn created the global Internet (Capital I).

Terminology

- Capitalization of Internet
  - With an upper-case I, Internet means the global Internet we use every day.
  - With a lower-case i, internet means any internet or the internet layer.

Internetworking



Two Layers of Networking

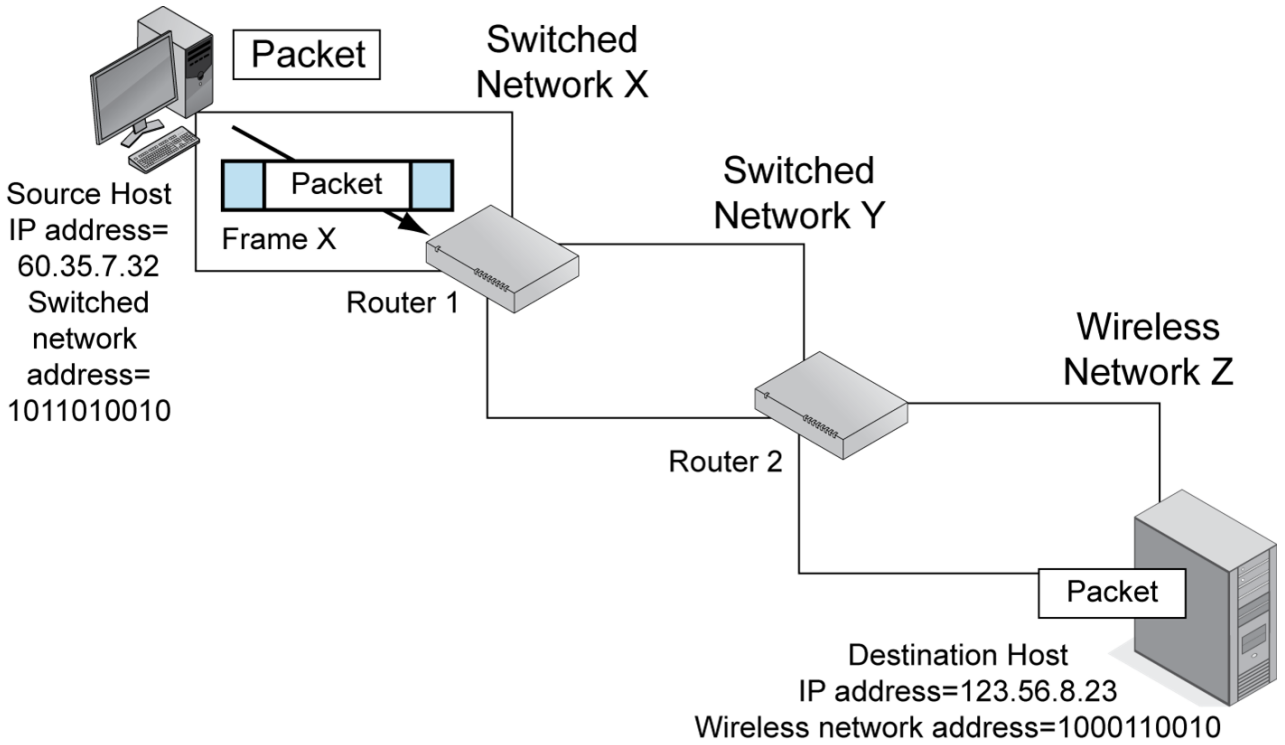
- Basically, Kahn and Cerf created a second layer of networking on top of single networks.
- This required the creation of a parallel set of concepts for single networks and internets.
- Single networks and internets use similar concepts but give these concepts different names.
- It is important for you to get this clear in your head.

Two Layers in Networking

Element	Single Networks	Internets
Emergence	First	Later
Addresses	Vary by network technology	32-bit IP addresses
Packets are called	Frames	Packets
Packet switches	Switches	Routers
End-to-end paths	Data links	Routes

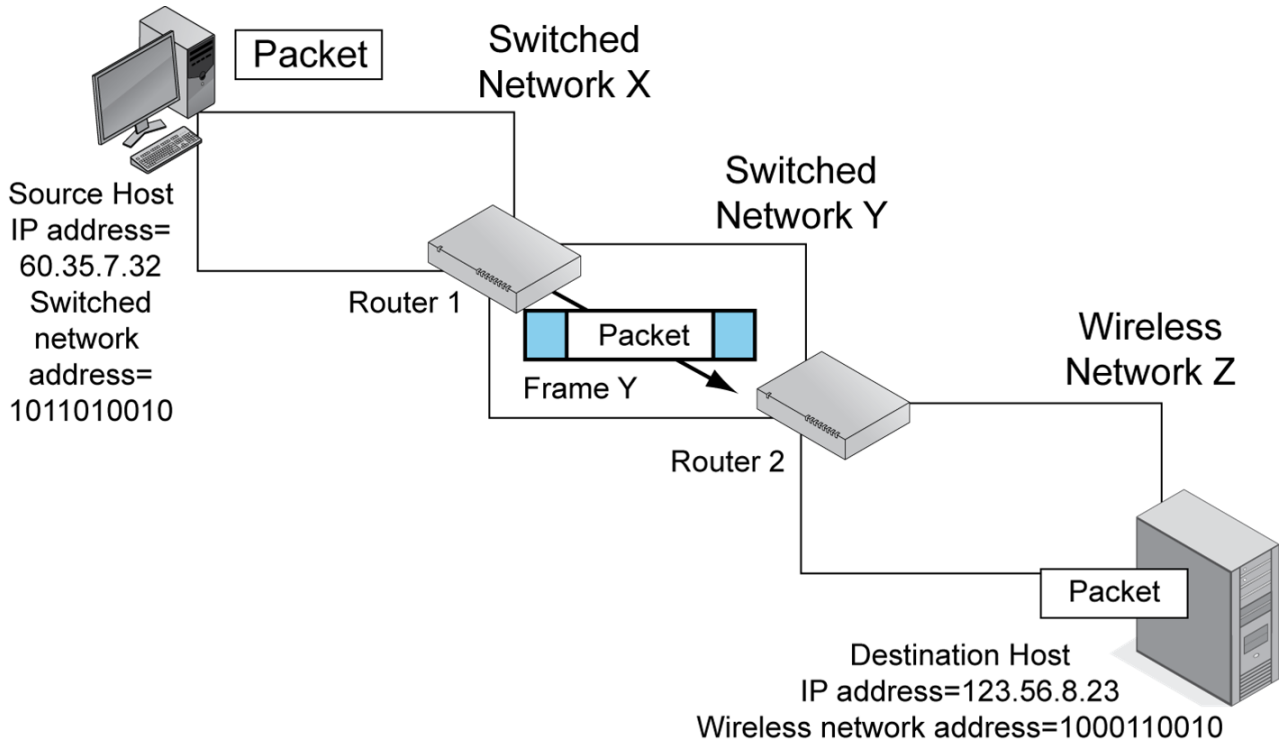
- Internetworking required adding a second layer of networking, duplicating concepts but with different names.

Packets and Frames



- In an internet, a single packetgoes all the way from the source host to the destination host.
- In each single network along the way, the packet is carried in a different frame.

Packets and Frames



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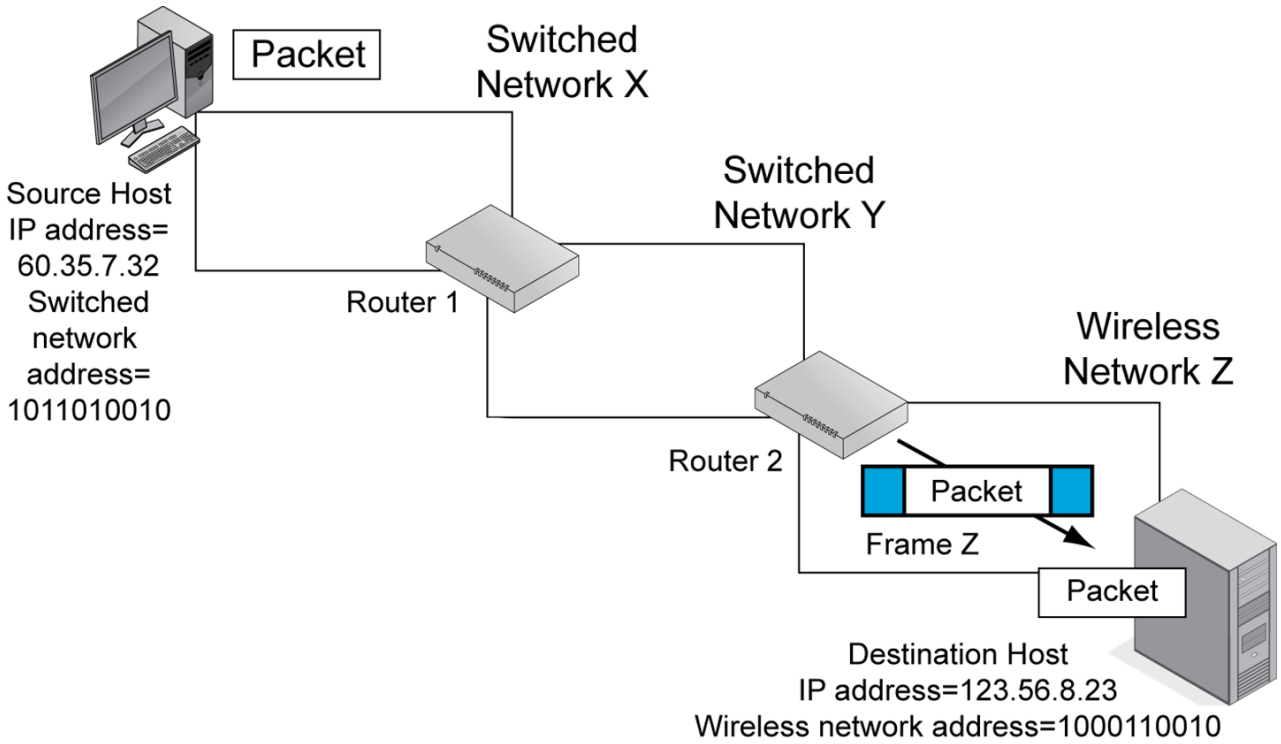
Packets and Frames



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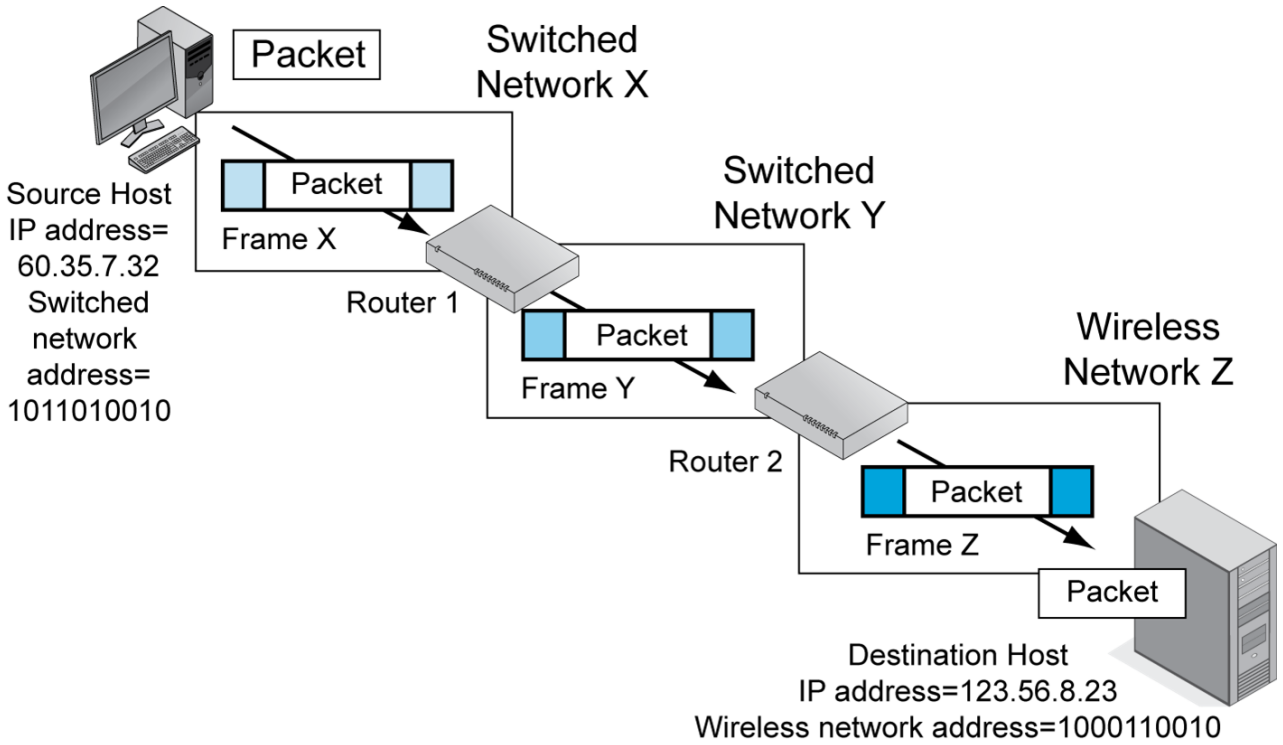
Packets and Frames



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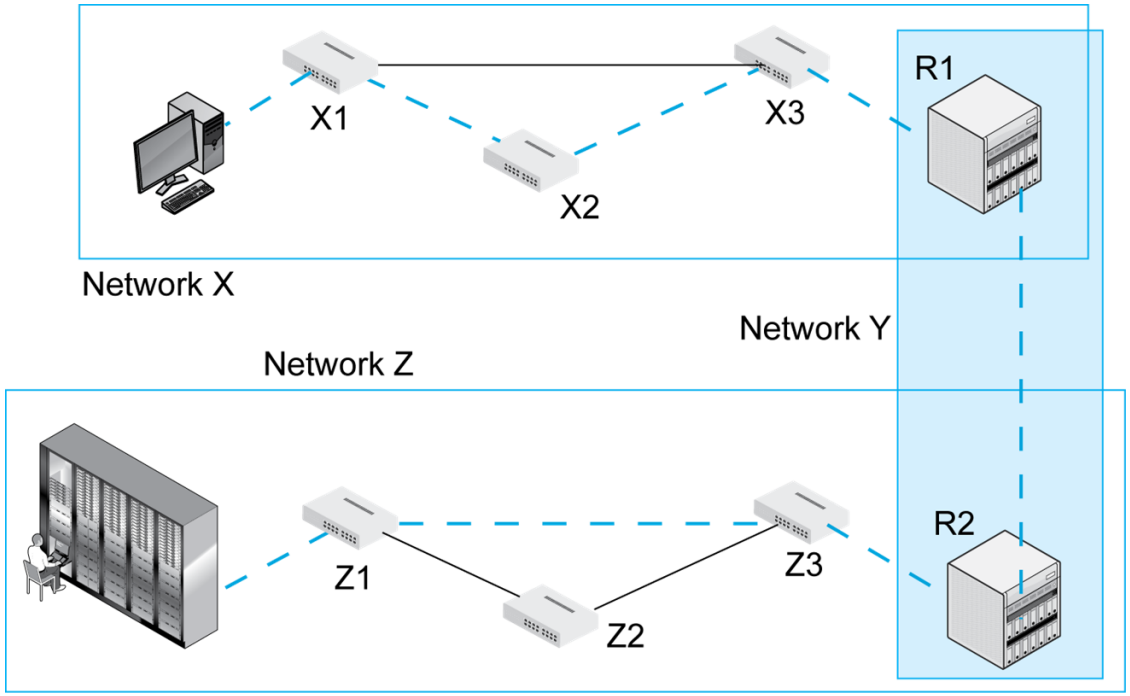
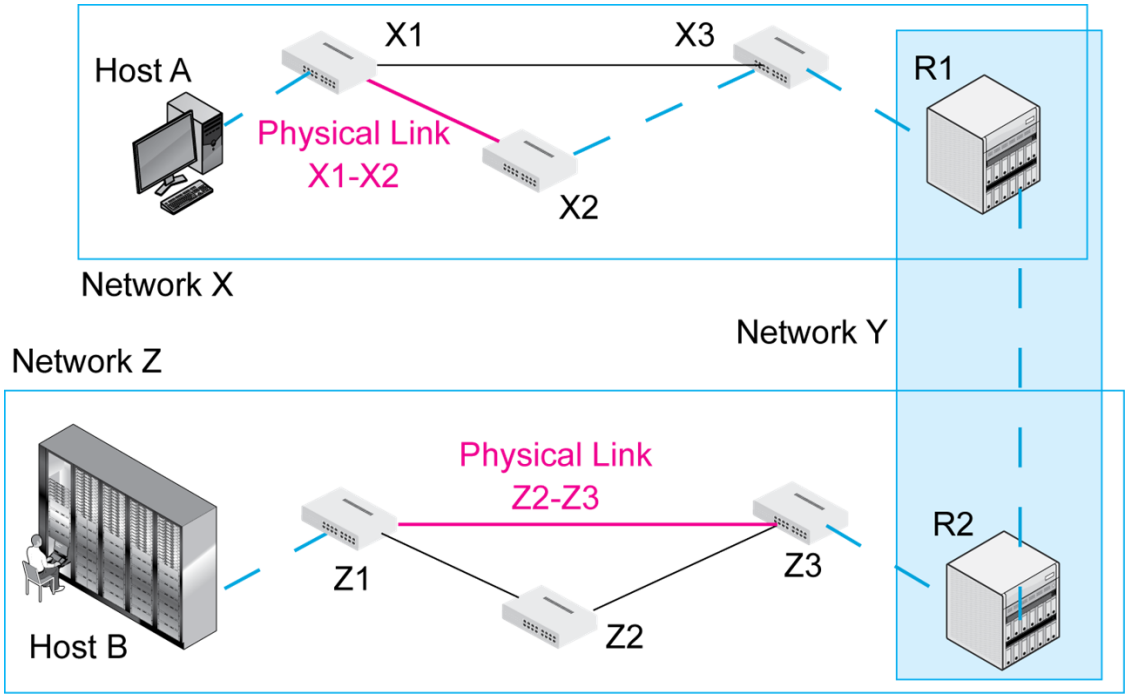
Physical Links, Data Links, and Routes



- Dashed line shows the path of a packet through the three networks.

Physical Links, Data Links, and Routes

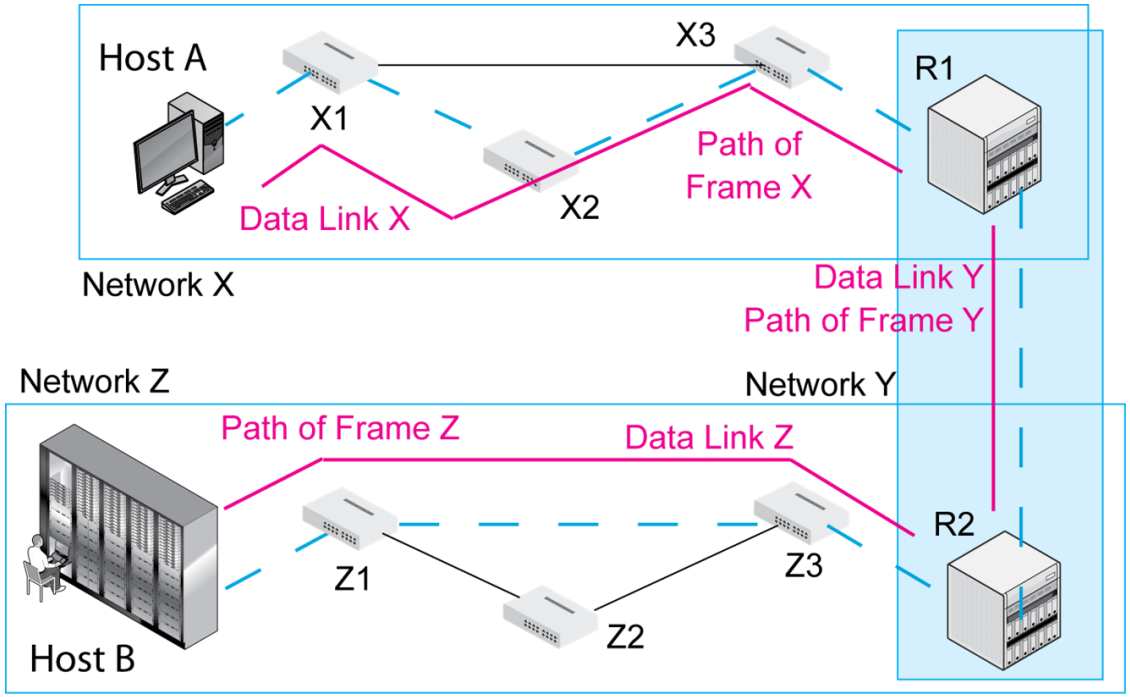


- Physical links connect adjacent devices, as noted earlier.

Example (5)

1. How many physical links are there between the two hosts?

Physical Links, Data Links, and Routes

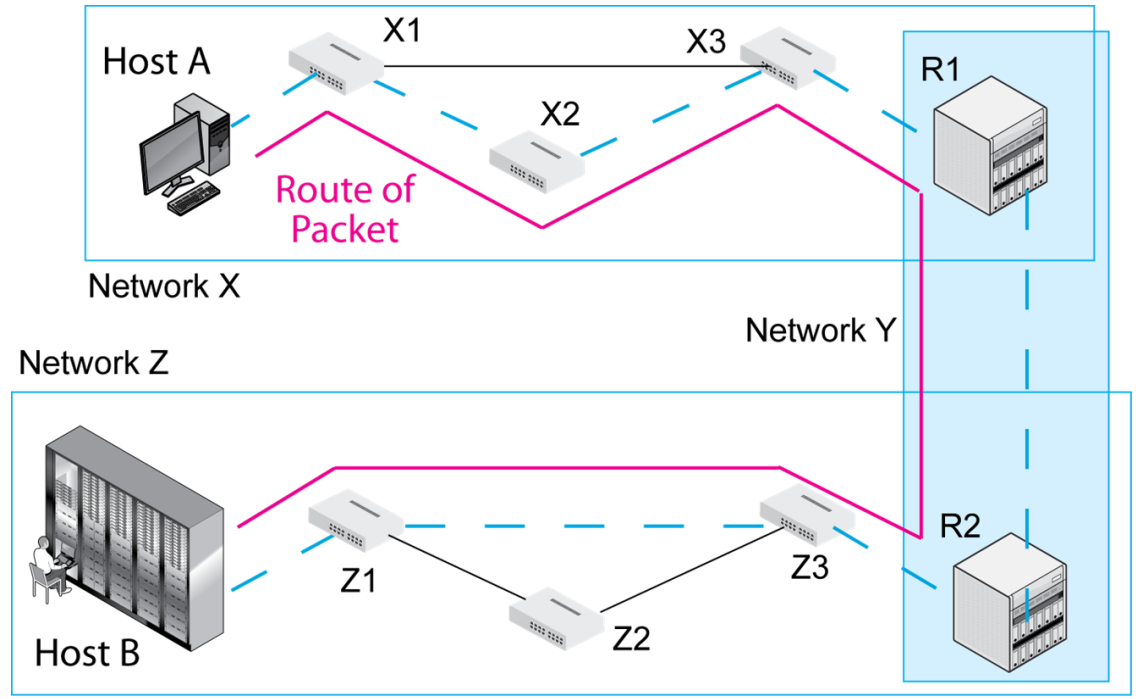


- A data link is the path of a frame through a single network, as noted earlier.

Example (6)

1. There is one data link per network. How many data links are in the figure?

Physical Links, Data Links, and Routes



- A route is a packet's path through an internet. Added for internets.

Example (7)

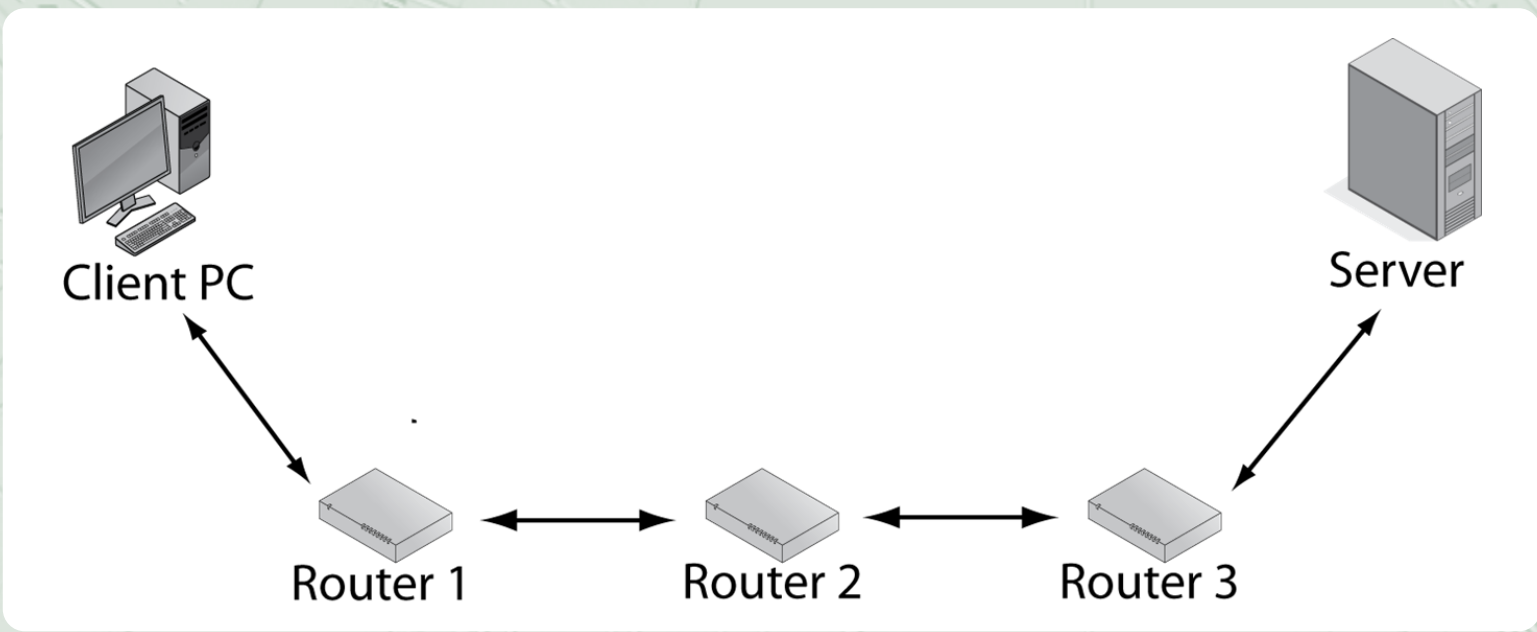
1. How many routes are there in the figure?

Physical Links, Data Links, and Routes
Questions

Example (8)

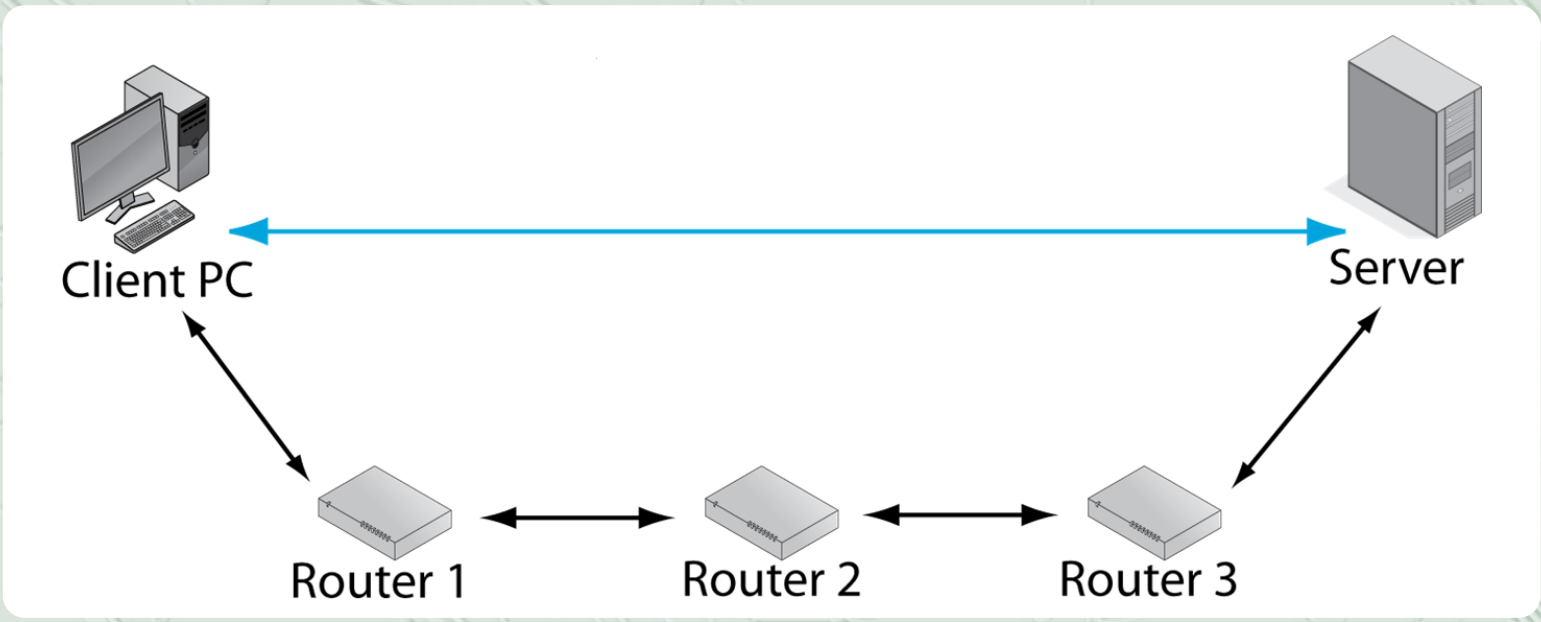
- Host P transmits a packet to Host Q.
- There are seven networks between the hosts.
  1. How many packets will there be along the way?
  2. How many frames will there be along the way?
  3. How many routes will there be along the way?
  4. How many data links will there be along the way?

The Internet and Transport Layers



- Internet Layer
  - Hop-by-Hop (host-router or router-router)
  - Packet organisation and forwarding

The Internet and Transport Layers



- Transport Layer
  - End-to-End (host-to-host)
  - Packet assembly and disassembly
  - Error correction, packet sequencing, congestion control

Networking Layers

Number	Name	Broad Purpose	Specific Purpose
5	Application	Communication between applications	Same
4	Transport		
3	Internet		
2	Data Link		
1	Physical		

Networking Layers

Layer	Name	Broad Purpose	Specific Purpose
5	Application		
4	Transport	Internet Transmission	Application message fragmentation, error correction, congestion reduction, etc.
3	Internet		Transmission of packet across an internet. Packet formats, router operation.
2	Data Link		
1	Physical		

Networking Layers

Layer	Name	Broad Purpose	Specific Purpose
5	Application		
4	Transport		
3	Internet		
2	Data Link	Single-network transmission (switched or wireless)	Connection across a single network. Frame formats and switch operation.
1	Physical		Physical connections between adjacent devices

Core TCP/IP Standards

Core TCP/IP Standards

Layer	Standards		
Application	HTTP	SMTP	etc.
Transport	Transmission Control Protocol (TCP)	User Datagram Protocol (UDP)	
Internet	Internet Protocol (IP)		

- The TCP/IP Standards Govern the Internet and Many Corporate Internets.

Core TCP/IP Standards

- IP
  - Internet layer protocol
  - Unreliable best-effort internet layer operation
    - No guarantee that packets will be delivered.
    - No guarantee that if packets arrive, they will be in order.

Core TCP/IP Standards

- TCP
  - Transport layer protocol
  - TCP messages are called segments
  - Provides transport layer functionality to fix problems
  - Error correction, and so on
- UDP
  - The other transport layer protocol
  - Messages are called datagrams
  - Unreliable, so used when reliability is not desired

The Internet Evolves

- 1977
  - First experimental connection of three networks
  - (Two wireless and the ARPANET)
- 1970s
  - Internet opened to outside network for e-mail exchanges

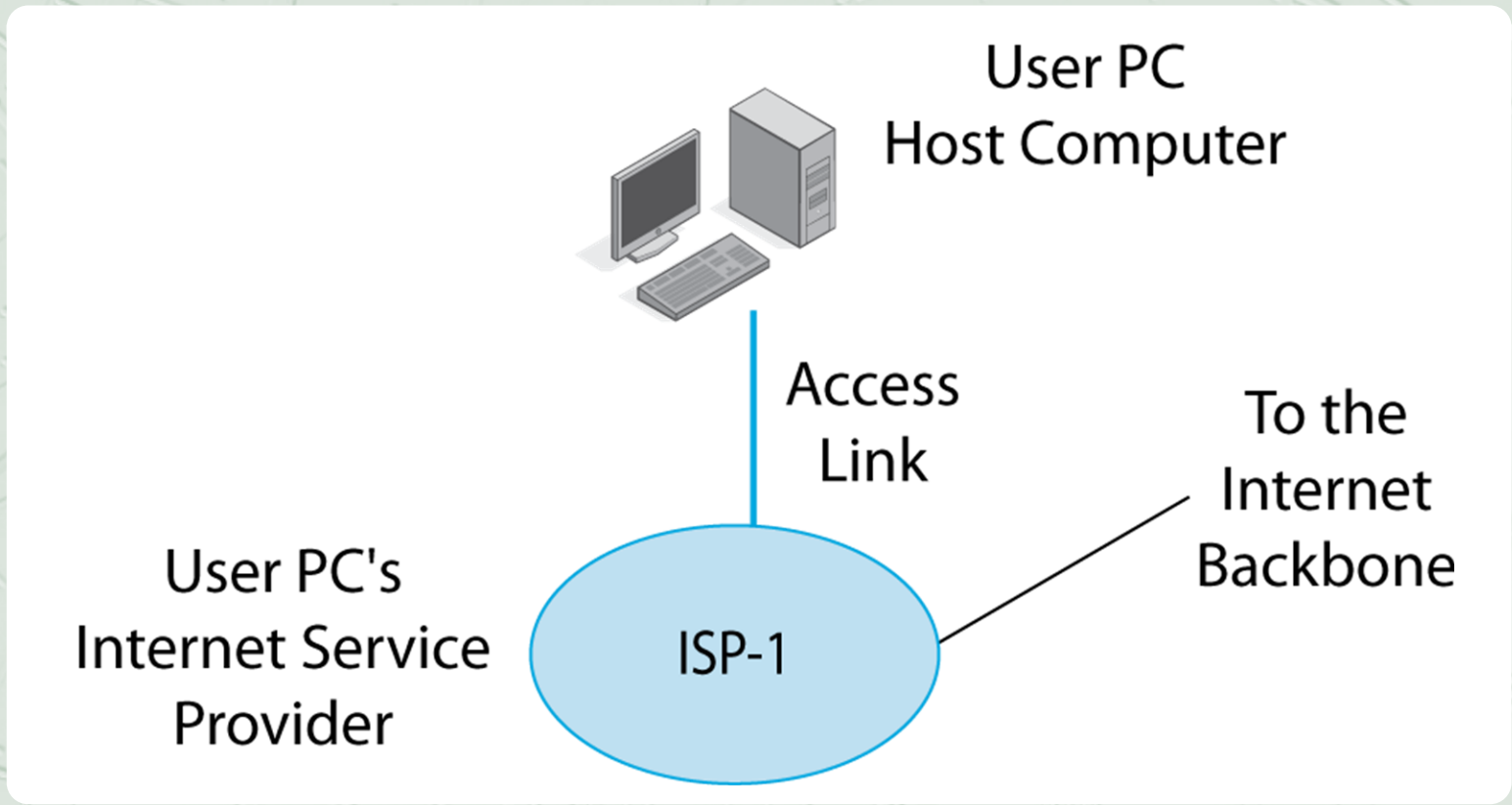
The Internet Evolves

- TCP/IP standards evolved in the 1970s.
  - Hosts could run either TCP/IP or NCP standards.
- 1983
  - All hosts were required to run TCP/IP.
- NSFNET
  - In the 1980s, the NSFNET funded by NSF was the core of the Internet.
  - NSF had an Acceptable Use Policy barring commercial activity such as e-commerce.

The Internet Evolves

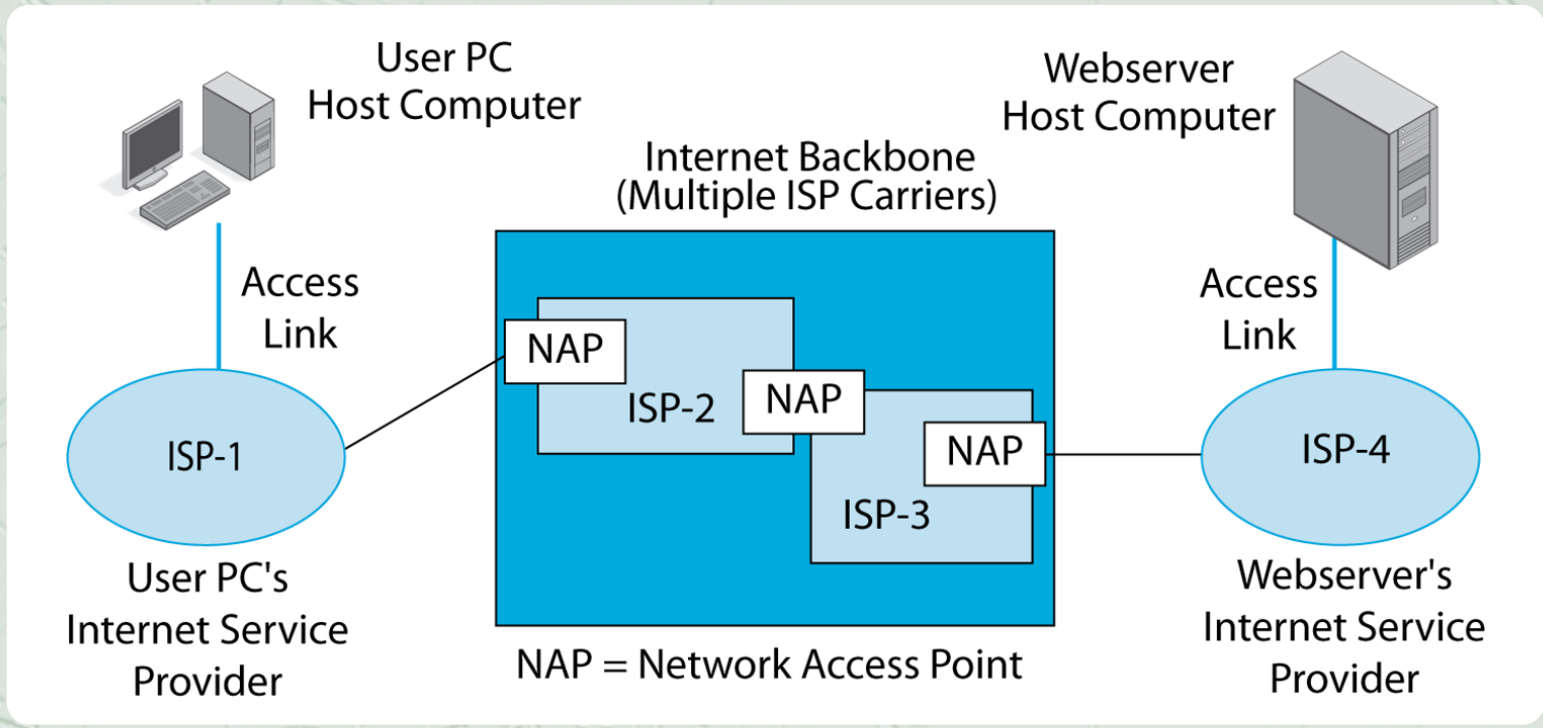
- 1995
  - NSFNET replaced by commercial ISPs.
  - No longer was e-commerce forbidden.
  - The e-commerce revolution began.
  - The World Wide Web became popular just before that.

The Internet Today



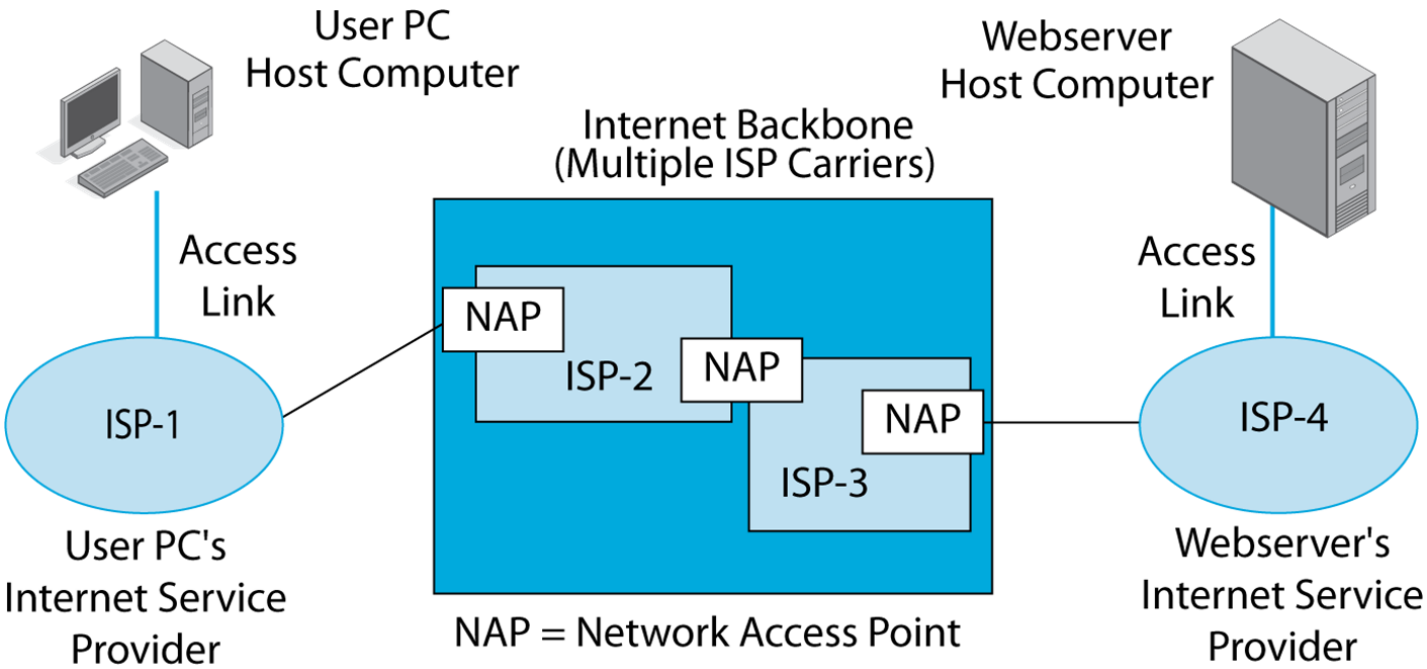
- To use the Internet, you need an Internet service provider and an access line to your ISP.
- Your ISP gives you access and carries your packets.
- Organizations also need ISPs.

The Internet Today



- ISPs collectively comprise the Internet backbone.
- They interconnect at Network Access Points (NAPs) to exchange packets.

The Internet Today



Example (9)

1. Trace the path packets take from the User PC to the Webserver.

Internet Supervisory Protocols

Beyond packet delivery

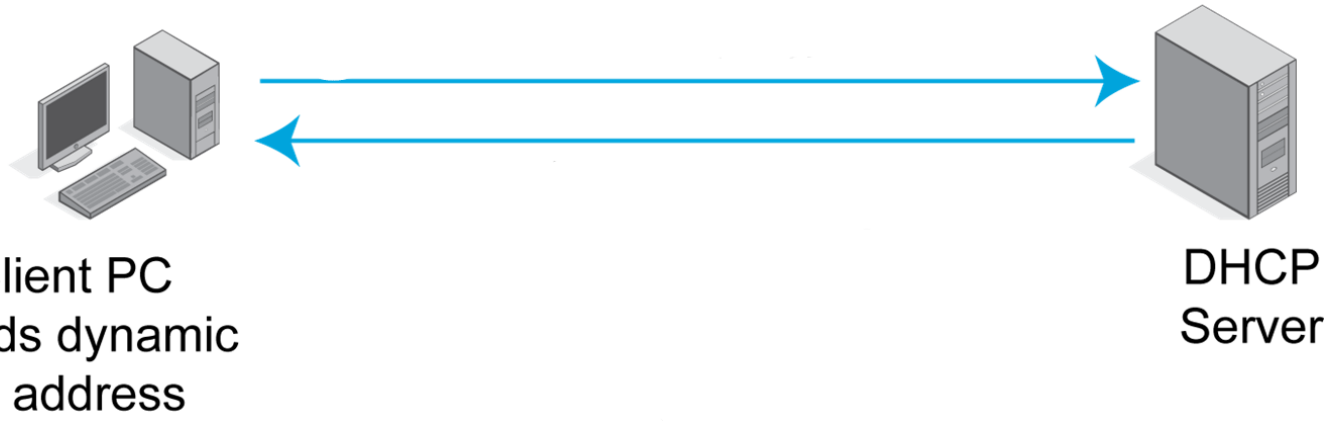
- IP, TCP, and UDP are standards for delivery packets.
- TCP/IP also has supervisory protocols.
  - To handle things beyond packet delivery.
  - Managing IP addresses.
  - Error handling, and so on.
  - We will look at two supervisory protocols in this chapter.
  - We will look at many more in Chapter 10.

Dynamic Host Configuration Protocol

- The Situation
  - A client PC boots up.
  - It realizes that it does not have an IP address.
  - This would be like not having a telephone number.
  - The client PC calls a Dynamic Host Configuration Protocol Server.
  - The DHCP server gives the client PC an IP address to use temporarily (and other configuration information).

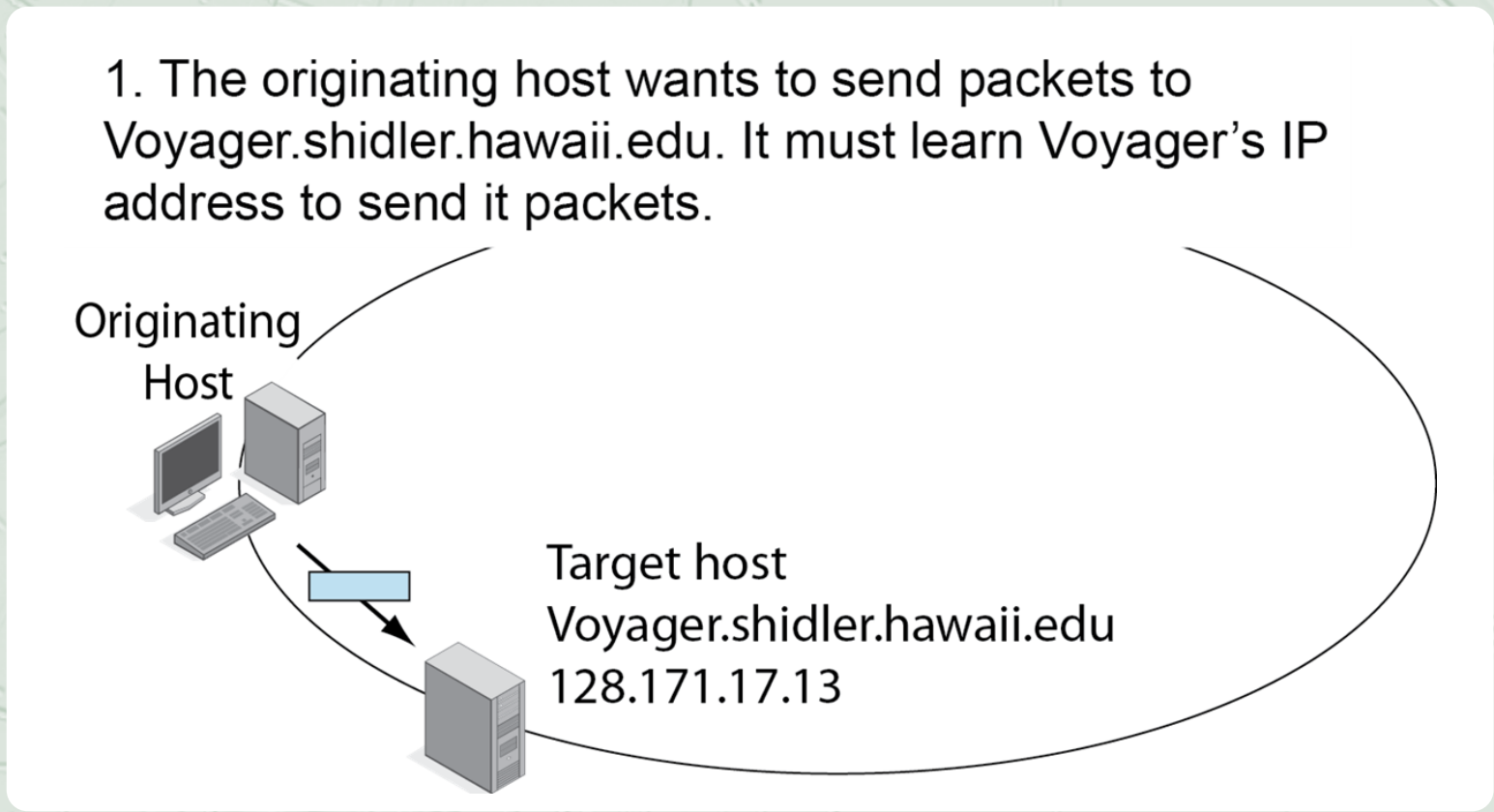
Dynamic Host Configuration Protocol

- DHCP Request message:
  - My network address is F102A
  - Please give me a 32-bit IP address



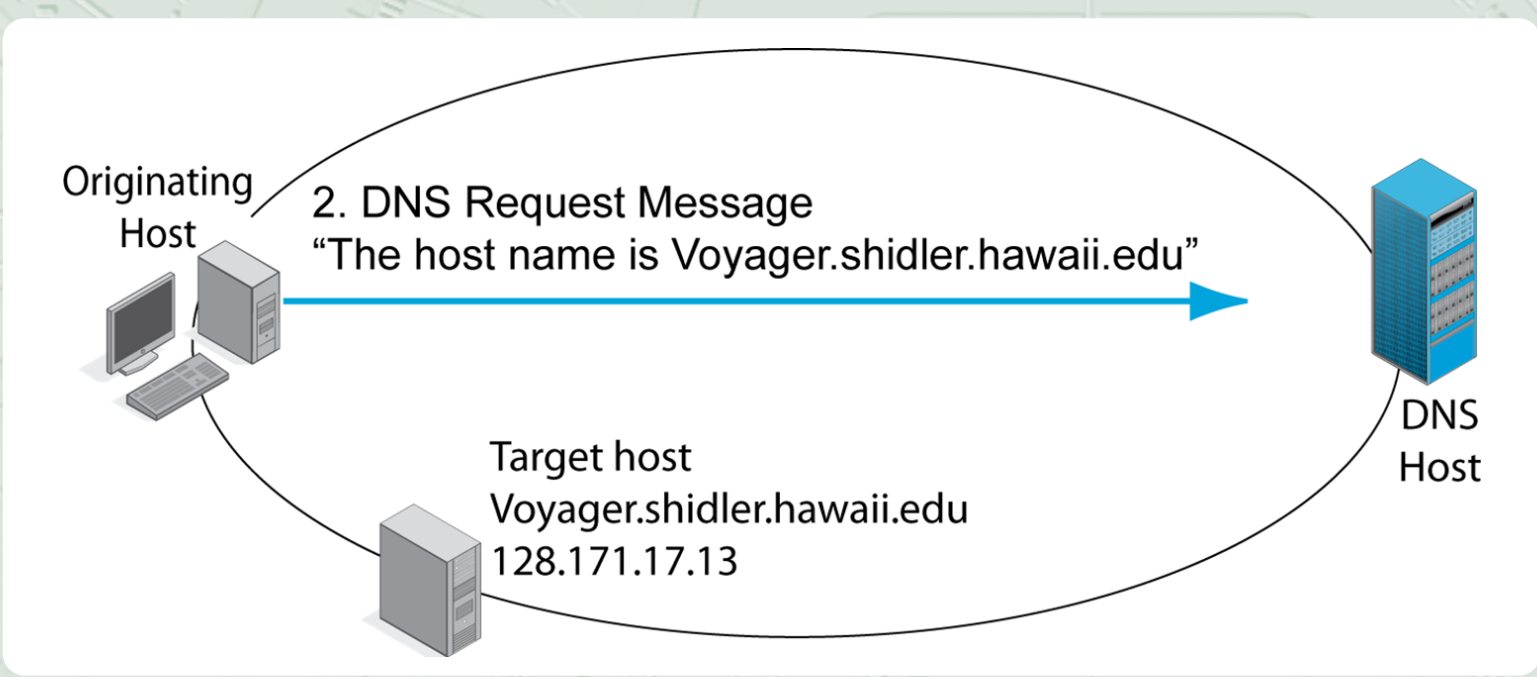
- DHCP Response message:
  - Your 32-bit IP address is . . .
  - Here is additional configuration information
  - The IP address of your default router;
  - The IP addresses ofyour DNS servers:
  - . . .

The Domain Name System (DNS)



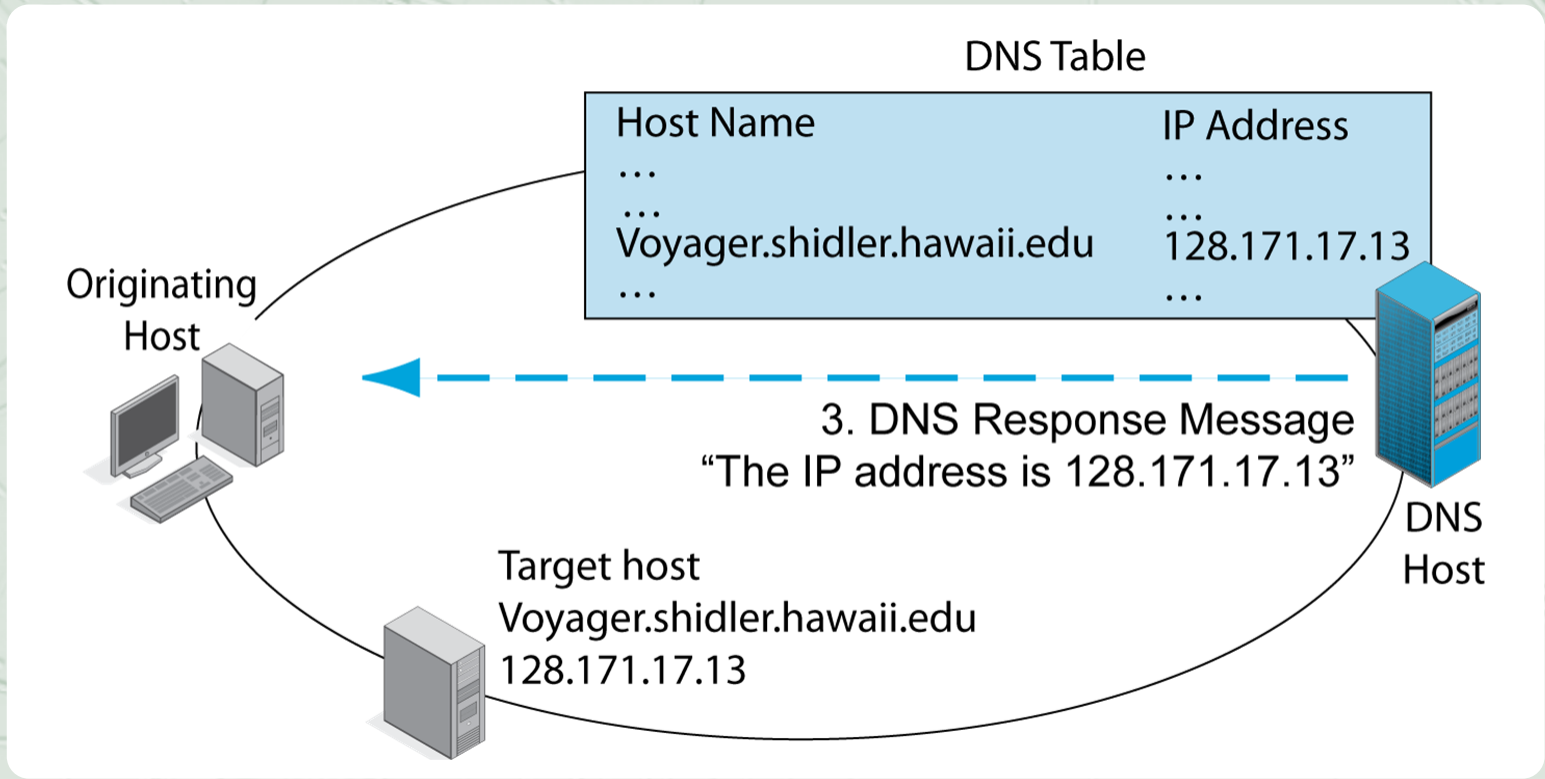
- The originating host must contact a DNS server to find Voyager's IP address.

The Domain Name System (DNS)



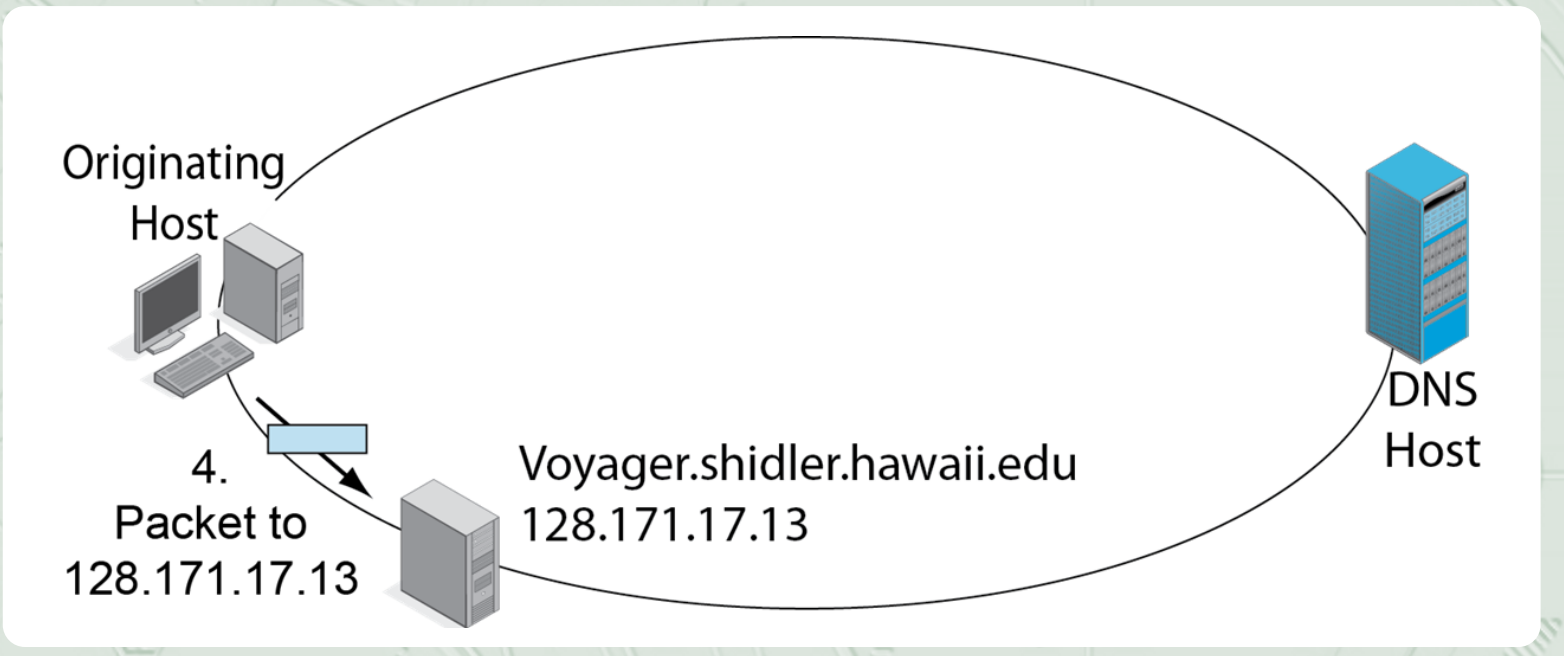
- The DNS host is like a telephone directory.
- You send it the host name for which you need an IP address.

The Domain Name System (DNS)



- The DNS server looks up the IP address and sends it back.

The Domain Name System (DNS)



- The originating host can now send packets to the target host.
- No DNS lookup is needed for the rest of the communication between the originating host and the target host.

DHCP versus DNS Question

- Both DHCP and DNS send you an IP address.
- In DHCP, for what device is this the IP address?

Example (10)

1. In DNS, for what device is this the IP address?

LANs versus WANs

LANs versus WANs

Category	Local Area Networks	Wide Area Networks
Abbreviation	LANs	WANs
Definition	On customer premises (apartment, office, building, campus, etc.)	Between sites within a corporation or between corporations

LANs versus WANs

Category	Local Area Networks	Wide Area Networks
Implementation	Self	Carrier with rights of way
Ability to choose technology	High	Low
Need to manage the technology after installation	High	Low

LANs versus WANs

Category	Local Area Networks	Wide Area Networks
Cost per bit transmitted	Low	High
Therefore typical transmission speed	Usually 100 Mbps to 10 Gbps	Usually about 256 kbps to 50 Mbps

- Longer transmission distances means a higher cost per bit transmitted.
- As unit price increases, the number of units demanded falls. (You can't afford to buy as much.)

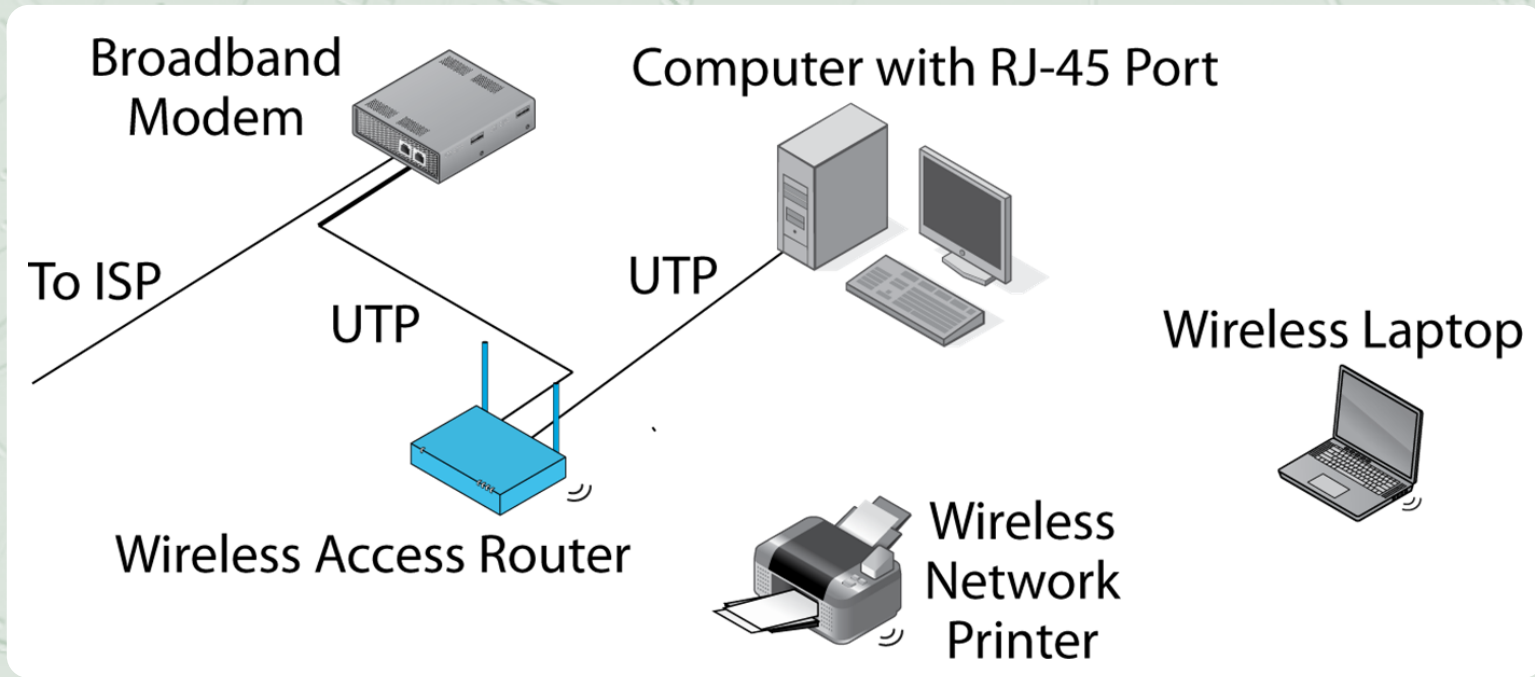
LANs versus WANs

Category	Local Area Networks	Wide Area Networks
Can use switched or wireless network technology?	Yes	Yes
Can use internet (routed) technology?	Yes	Yes

- Both LANs and WANs can be either single switched (or wireless) networks or internets.

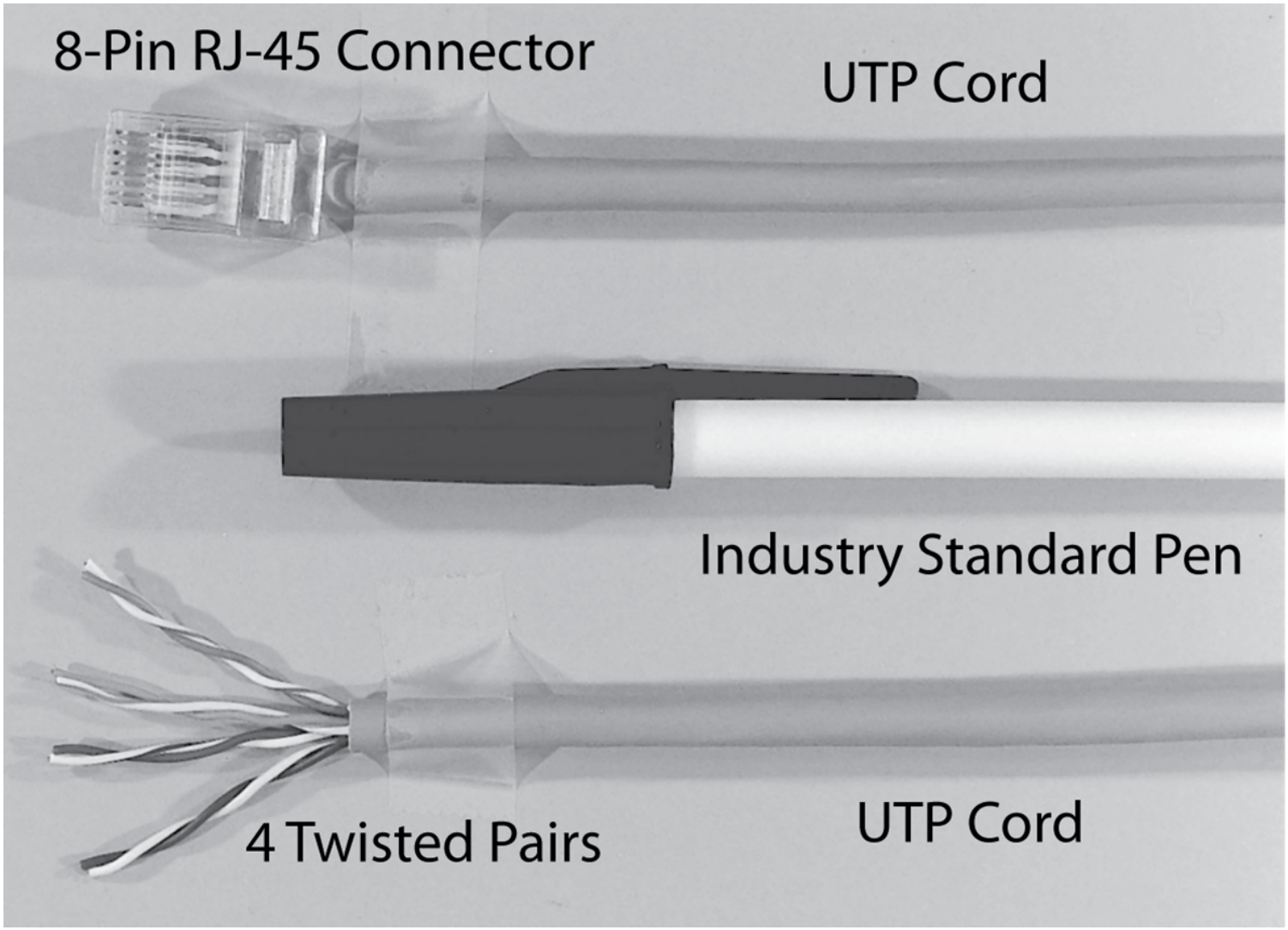
A Small Home Network

A Small Home Network

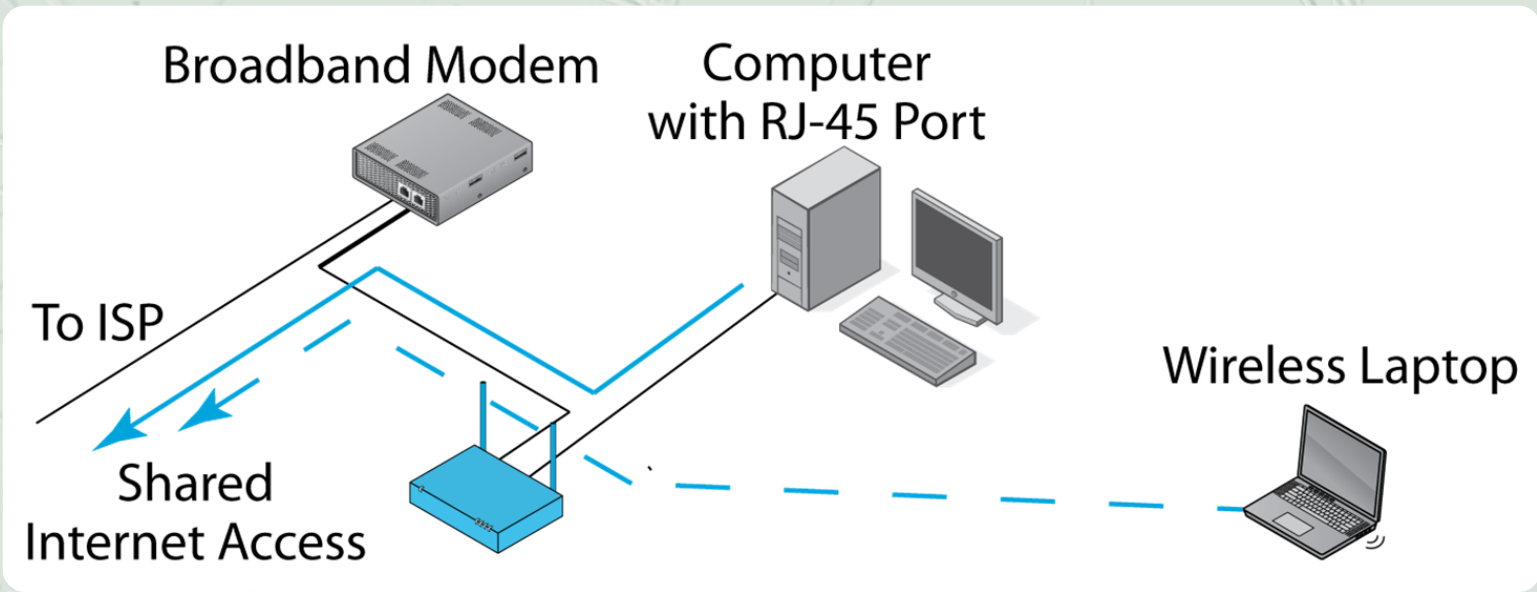


- Hardware Components

Unshielded Twisted Pair (UTP) Wiring

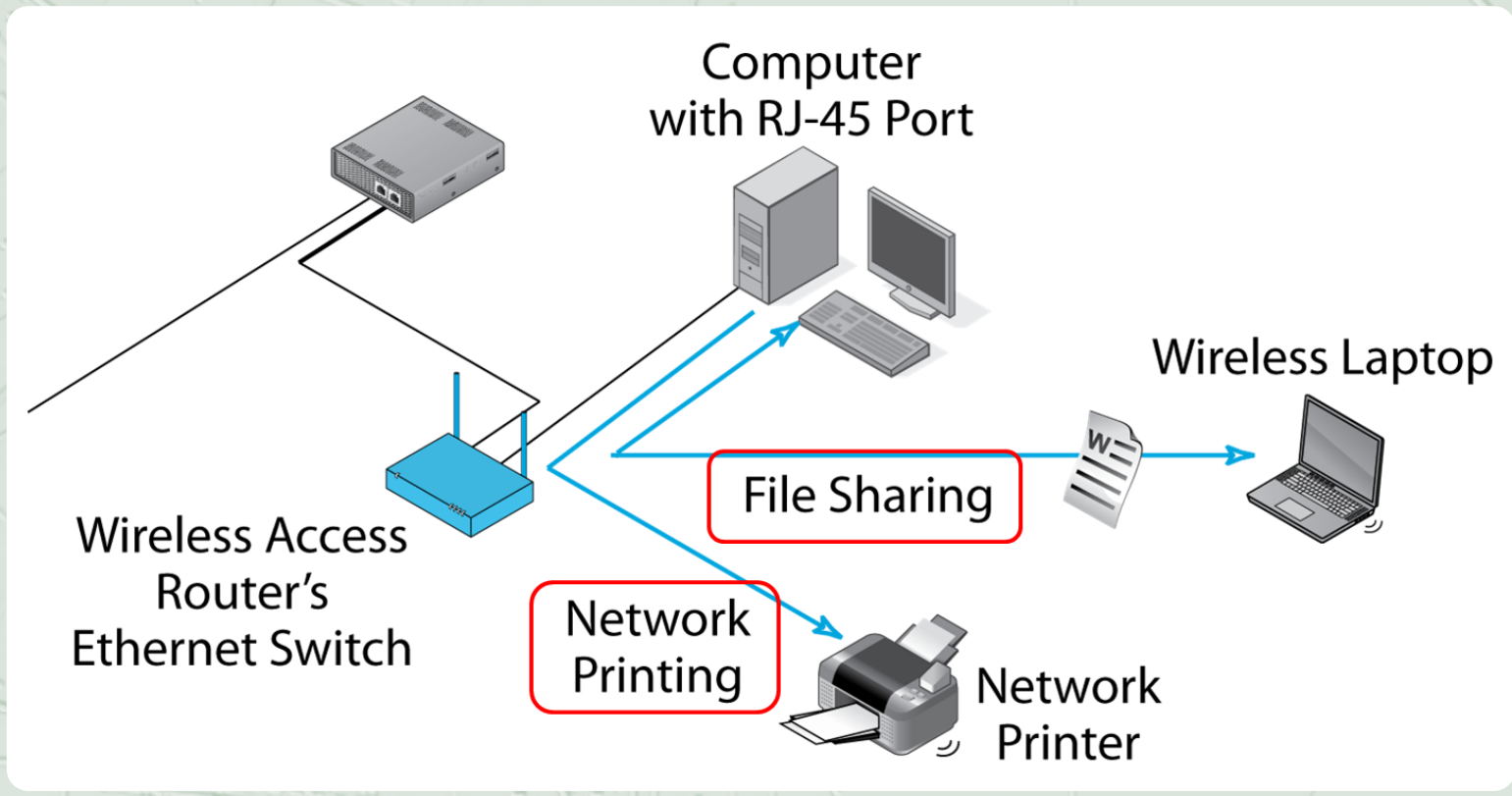


A Small Home Network



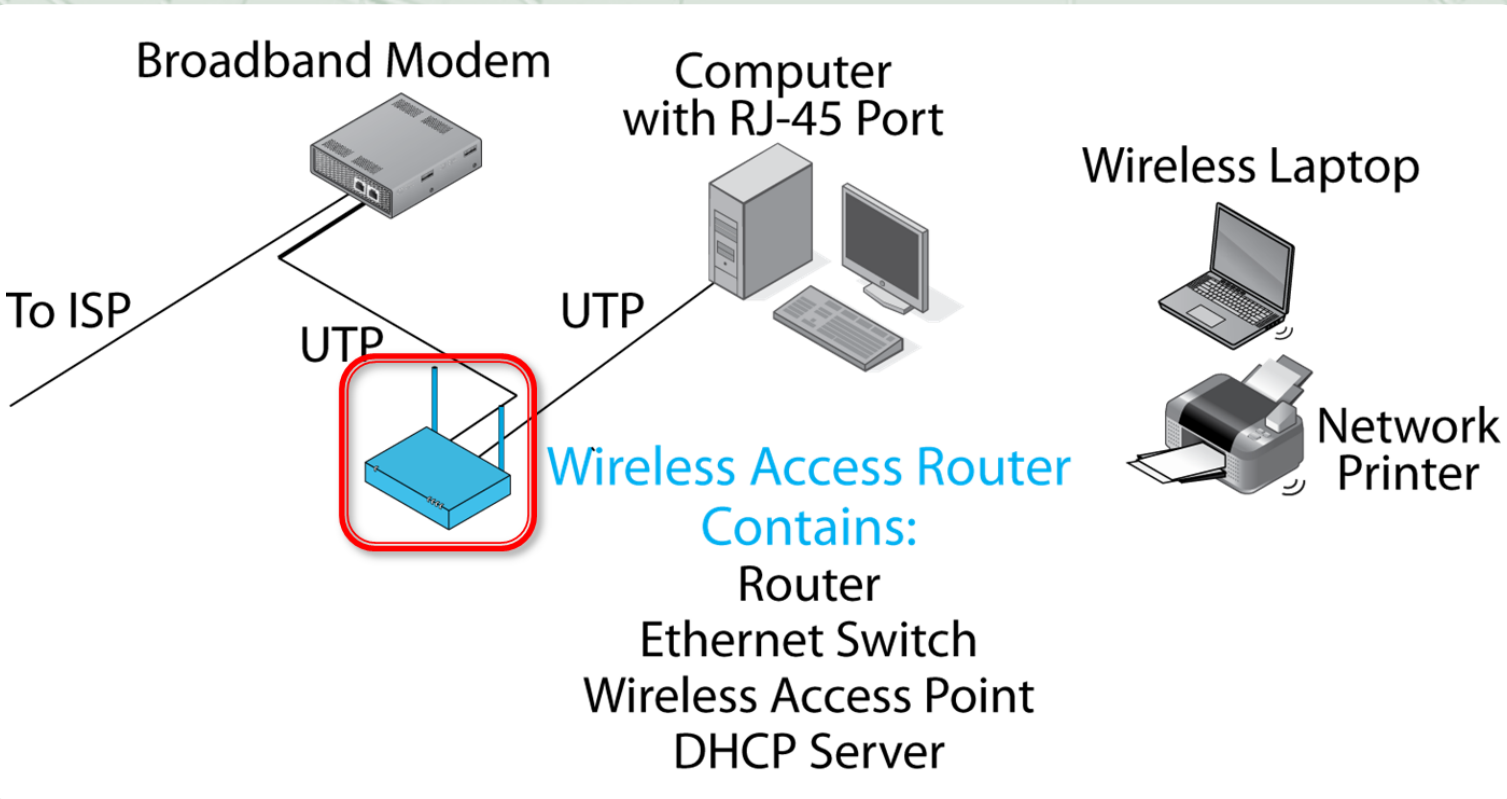
- Application: Shared Internet Access

A Small Home Network



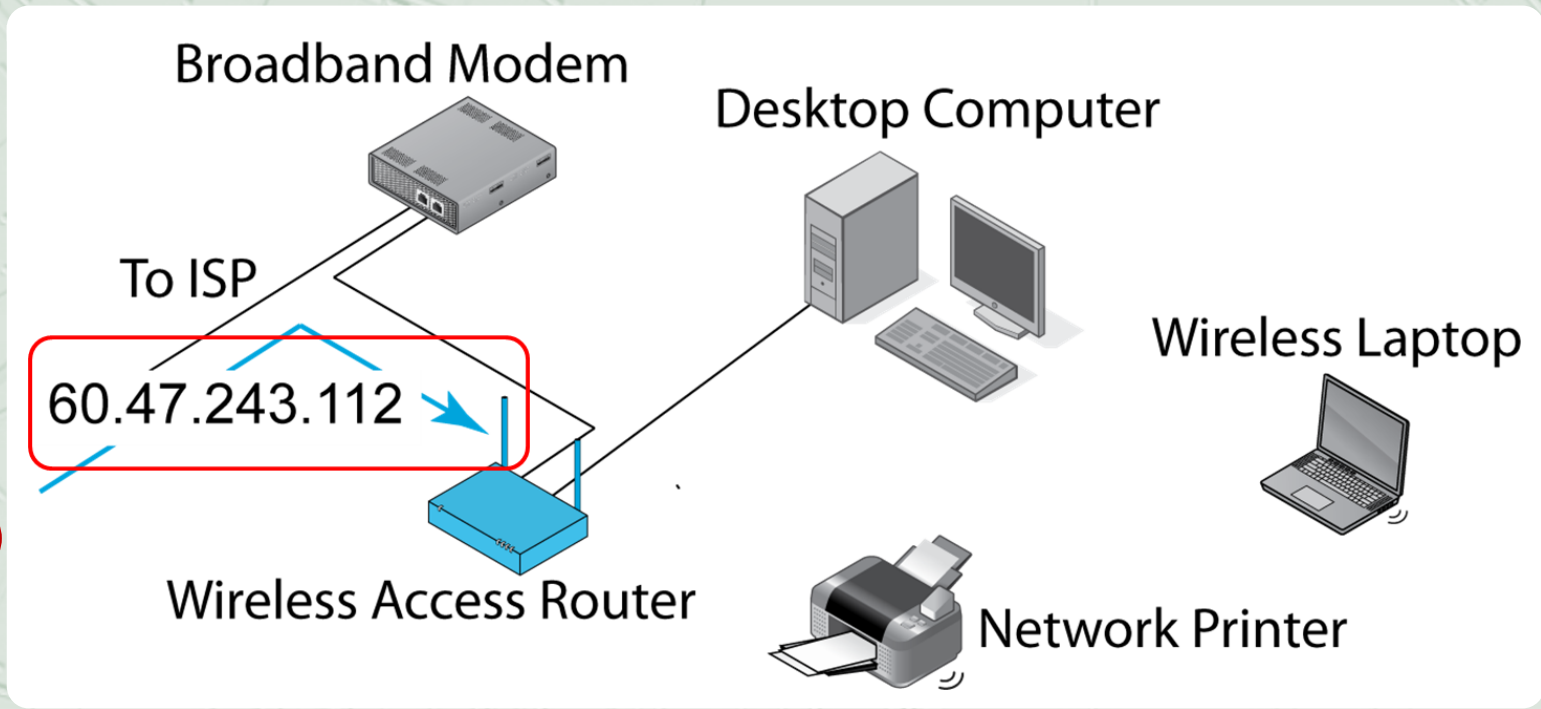
- Applications: File and Printer Sharing within a Home Network

A Small Home Network



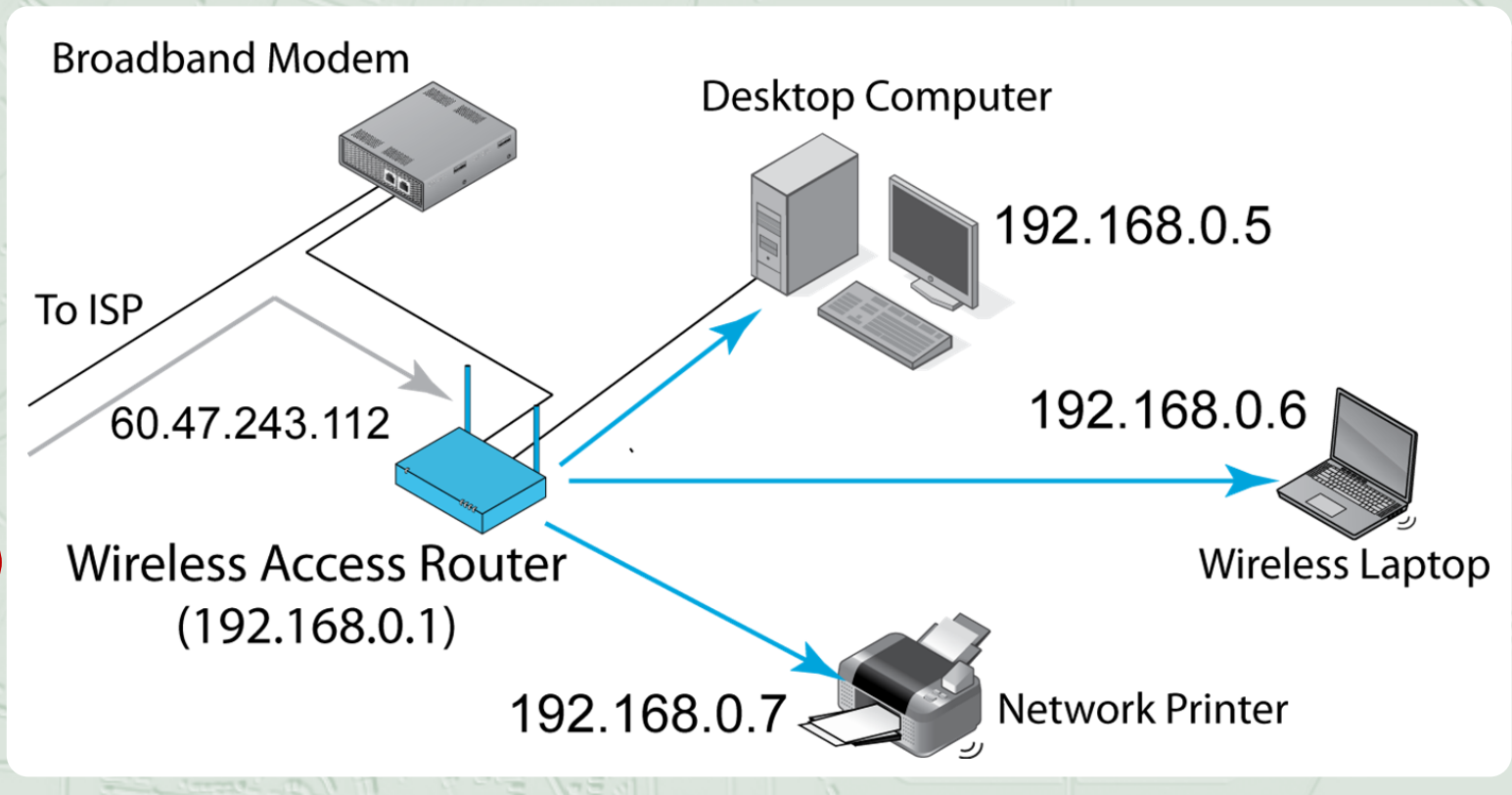
- The Access Router is far more than a router.

DHCP



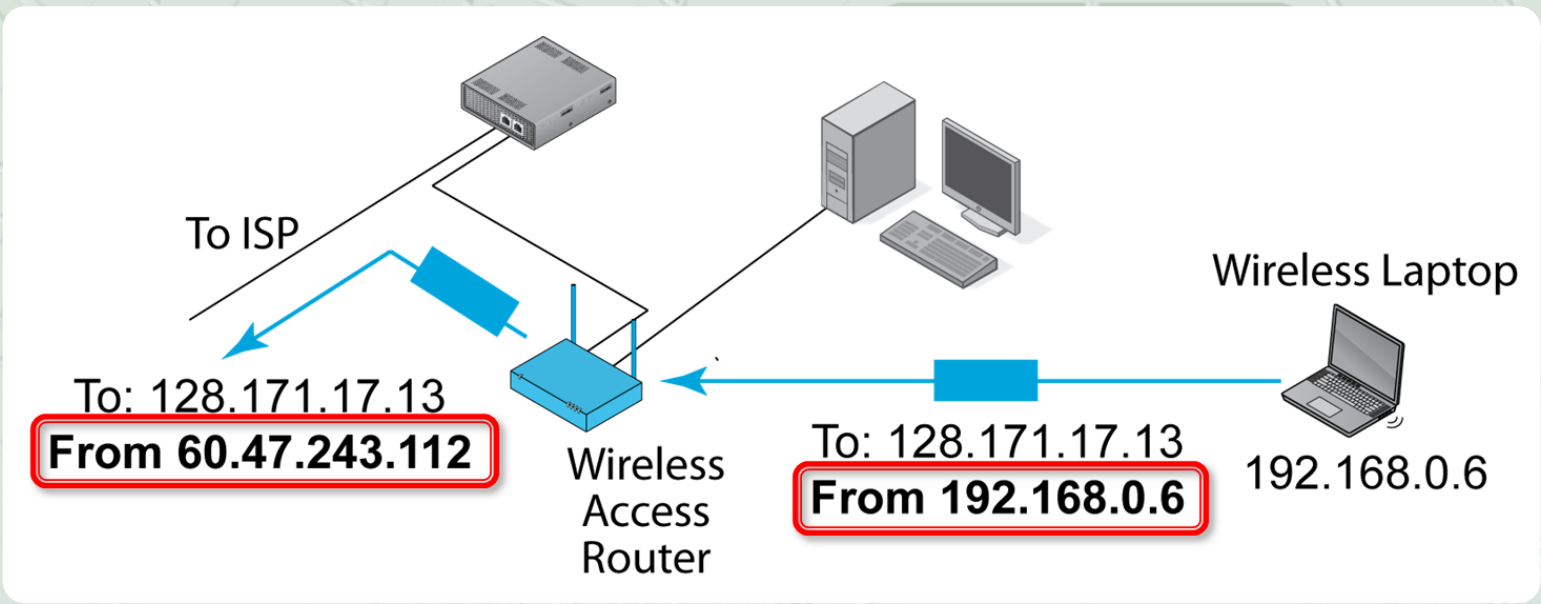
- The ISP's DHCP server gives your home a single IP address.
- In this case, it is 60.47.243.112.

DHCP



- Your access router has a DHCP server.
- It gives each device in the home a different IP address.

Network Address Translation (NAT)



- Access router's NAT function translates between internal and external IP addresses.

The Next Lecture

- Lecture 1 introduced the critical concept of standards.
- Lecture 2 looks at standards in more depth.
  - It will look at major characteristics of standards, such as the syntax of messages.
  - It will focus on the data link, internet, transport, and application layers, which work by sending structured messages.