MOBILE COMPUTING

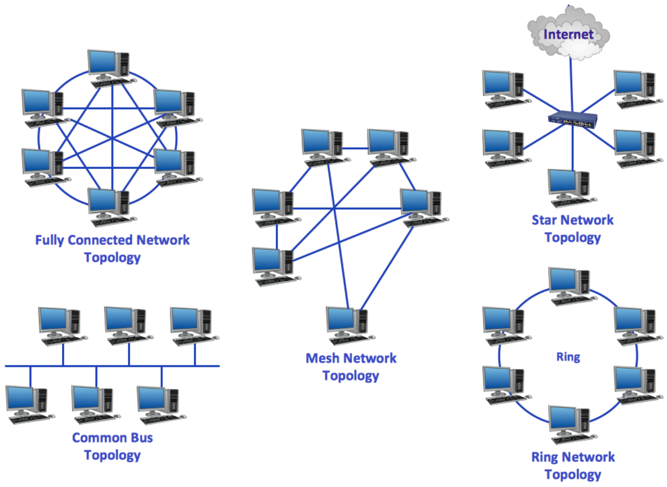
CSE 40814/60814

Spring 2021

Computer Network Terminology

- **Network:** group of computers and associated devices that are connected by communication facilities
- **Wide Area Network (WAN)**: world-wide (Internet)
- **Metropolitan Area Network (MAN):** city-scale
- **Local Area Network (LAN):** laboratory/office-scale (Ethernet)
  - **WLAN:** wireless LAN (Wi-Fi)
  - **WPAN:** wireless personal area network (Bluetooth)
  - **WBAN:** wireless body area network
- **Packet:** basic unit that is transferred over a network

Network Topologies



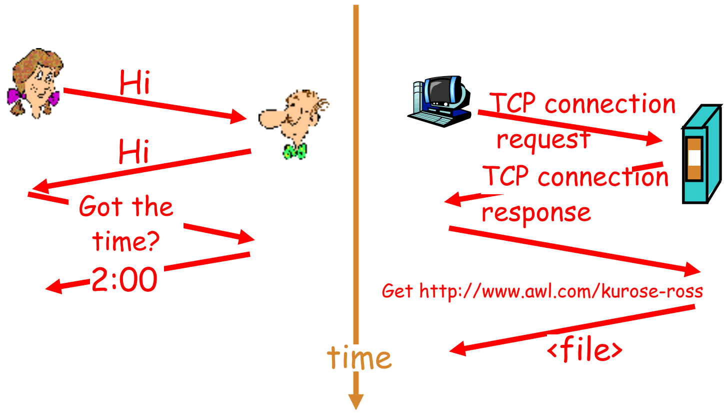
Network Protocols

- Protocols are the **building blocks** of a network architecture
- Formal standards and policies enabling communication
- IEEE (Institute of Electrical and Electronics Engineers): standardization
    - Example: Project 802
        - 802.3: Ethernet
        - 802.11: WLAN
        - 802.15: WPAN

Communication

- Who initiates communication?
- Order of communication?
- How long can I talk?
- How loud can I speak?
- Do I have to say something specific at beginning or end?
- Do I have to add meta information?
- What do I do if I get interrupted?
- What do I do if I was not understood?

Protocols



Hi

Hi

Got the time?

2:00

TCP connection request

TCP connection response

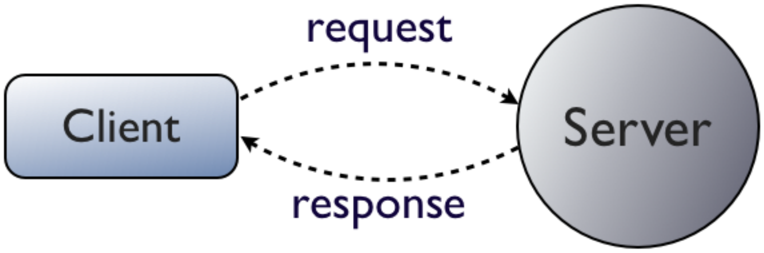
Get http://www.awl.com/kurose-ross

<file>

time

Client/Server Model

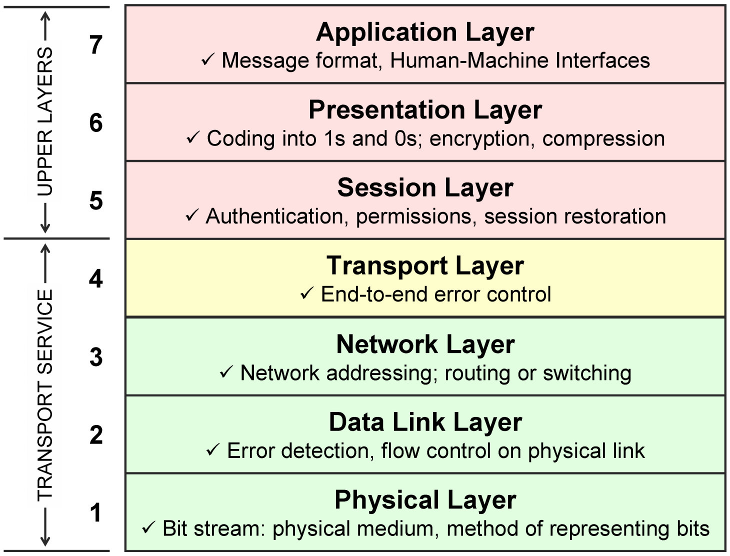
- Client: “active” (initiates communication)
- Server: “passive” (listens and responds)



Client/Server Model Examples

- HTTP (Hypertext Transfer Protocol)
- SMTP (Simple Mail Transfer Protocol)
- SSH (Secure Shell)
- DNS (Domain Name System)
- NFS/AFS (Network/Andrew File System)

Open System Interconnection (OSI)



UPPER LAYERS	7	**Application Layer** ✓ Message format, Human-Machine Interfaces
	6	**Presentation Layer** ✓ Coding into 1s and 0s; encryption, compression
	5	**Session Layer** ✓ Authentication, permissions, session restoration
TRANSPORT SERVICE	4	**Transport Layer** ✓ End-to-end error control
	3	**Network Layer** ✓ Network addressing; routing or switching
	2	**Data Link Layer** ✓ Error detection, flow control on physical link
	1	**Physical Layer** ✓ Bit stream: physical medium, method of representing bits

ISO/OSI Model

- International Standardization Organization Open System Interconnection
- 7-Layer Protocol
- Internet Protocol
- TCP/IP Protocol
- Why “layered” approach?
  - An explicit structure for dealing with a complex system
  - Simplifies the design process
  - Modularity of layers eases maintenance and updating of system components
  - Accommodates incremental changes

ISO/OSI Model

- Physical Layer
  - **Physical/electrical characteristics**
  - Cable type, length, connectors, voltage levels, signal durations, ...
  - Binary data (bits) as electrical or optical signals.
- Data Link Layer
  - **Defines when/how medium will be accessed for transmission**
  - Units typically called “frames”; error detection/correction; divided into sublayers, including: **MAC = Medium Access Control** (MAC address 6f:00:2b:23:1f:32)
- Network Layer
  - **IP = Internet Protocol**
  - **Addressing and routing** (IP address 147.94.123.15)

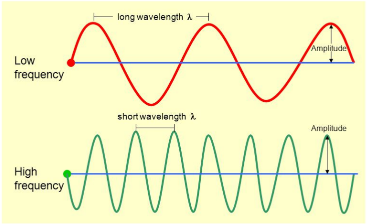
ISO/OSI Model

- Transport Layer
  - **UDP** (User Datagram Protocol)
  - **TCP** (Transmission Control Protocol)
  - Addressing (“**ports**”), error correction, flow control, congestion control
- Session Layer
  - Management of “sessions”
- Presentation Layer
  - Data translation, formatting, encryption, compression
- Application Layer
  - Interface between user applications and lower network services

Physical Layer (Layer 1)

- **Physical/electrical characteristics**
  - Cable type, length, connectors, voltage levels, signal durations, ...
  - Binary data (bits) as electrical or optical signals
  - Frequencies and wavelengths (wireless)

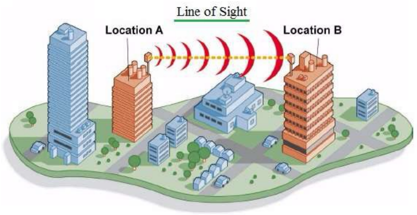
Waves



- Frequency and wave length
  - **λ = c/f**
  - wave length λ
  - speed of light c $\cong 3\text{x}10^8$m/s
  - frequency f

Frequencies for Mobile Communication

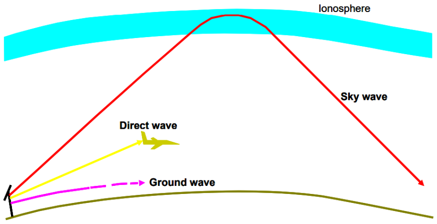
- Low Frequencies:
  - low data rates
  - travel long distances
  - follow Earth’s surface
  - penetrate objects and water (submarine communication)



- High Frequencies:
  - high data rates
  - short distances
  - straight lines
  - cannot penetrate objects (“**Line of Sight**” or **LOS**)

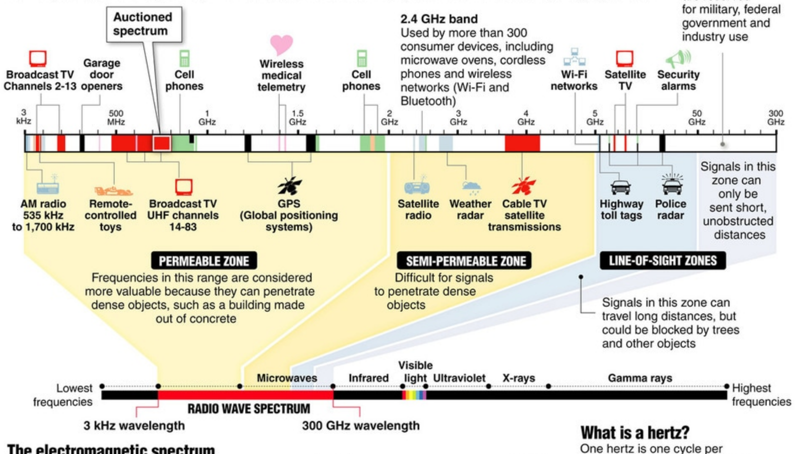
Propagation Behaviors

- **Ground wave (<2MHz):** follow earth's surface, long distances (submarine communication, AM radio)
- **Sky wave (2-30MHz):** reflected at ionosphere, around the world (intl. broadcasts, amateur radio)
- **Line-of-sight (>30MHz)**: LOS, straight line, waves are bent by atmosphere due to refraction (mobile phones, satellite, cordless)



Inside the radio wave spectrum

Almost every wireless technology – from cell phones to garage door openers – uses radio waves to communicate. Some services, such as TV and radio broadcasts, have exclusive use of their frequency within a geographic area. But many devices share frequencies, which can cause interference. Examples of radio waves used by everyday devices:



2.4 GHz band
Used by more than 300 consumer devices, including microwave ovens, cordless phones and wireless networks (Wi-Fi and Bluetooth)

Most of the white areas on this chart are reserved for military, federal government and industry use

Signals in this zone can only be sent short, unobstructed distances

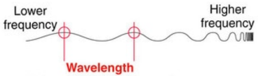
PERMEABLE ZONE Frequencies in this range are considered more valuable because they can penetrate dense objects, such as a building made out of concrete

SEMI-PERMEABLE ZONE Difficult for signals to penetrate dense objects

LINE-OF-SIGHT ZONES Signals in this zone can travel long distances, but could be blocked by trees and other objects

The electromagnetic spectrum

Radio waves occupy part of the electromagnetic spectrum, a range of electric and magnetic waves of different lengths that travel at the speed of light; other parts of the spectrum include visible light and x-rays; the shortest wavelengths have the highest frequency, measured in hertz



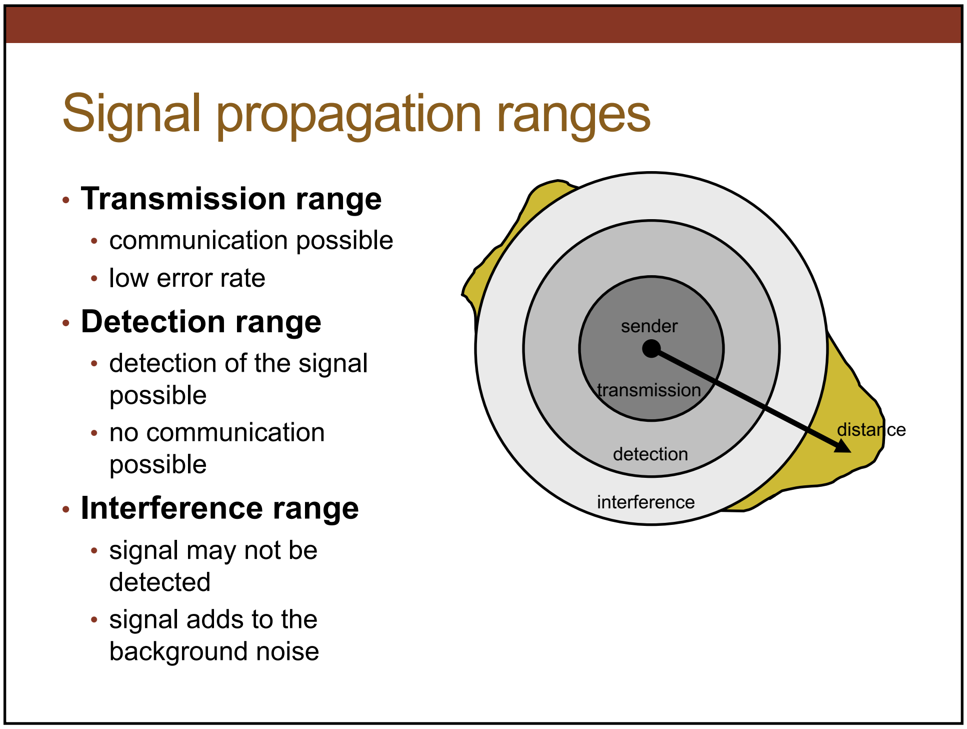
Distance from crest to crest

What is a hertz?

One hertz is one cycle per second. For radio waves, a cycle is the distance from wave crest to crest

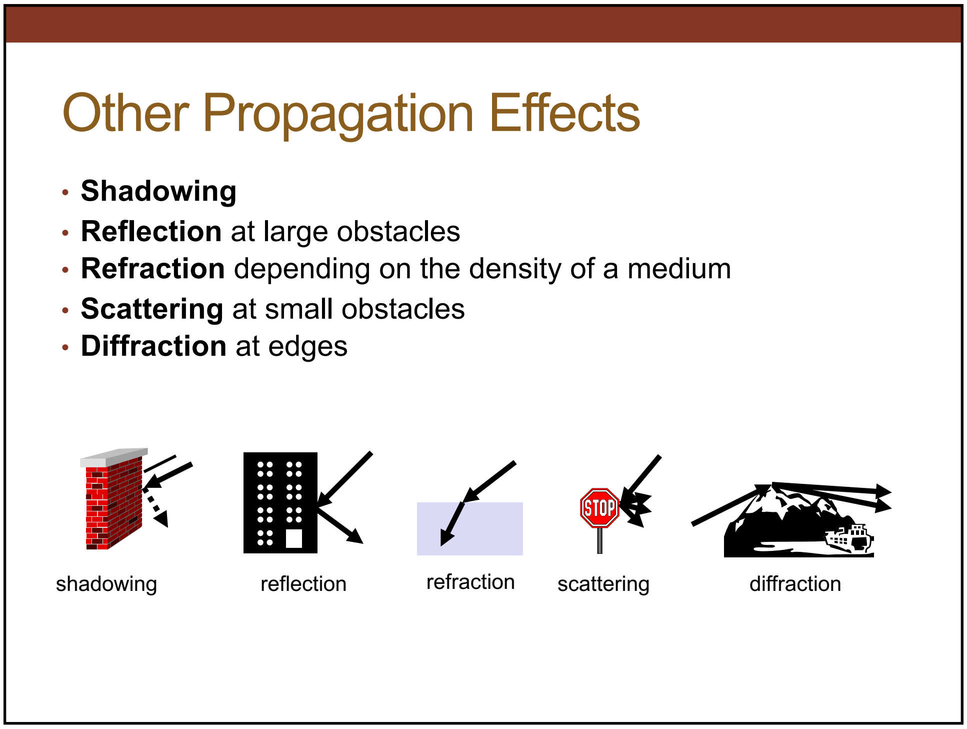
1 kilohertz (kHz) = 1,000 hertz
1 megahertz (MHz) = 1 million hertz
1 gigahertz (GHz) = 1 billion hertz

Source: New America Foundation, MCT, Howstuffworks.com
Graphic: Nathaniel Levine, Sacramento Bee



Signal propagation ranges

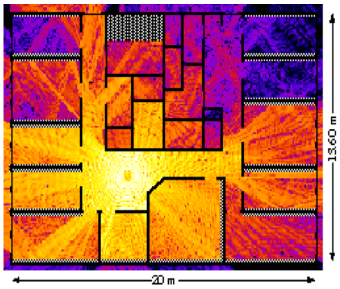
- **Transmission range**
  - communication possible
  - low error rate
- **Detection range**
  - detection of the signal possible
  - no communication possible
- **Interference range**
  - signal may not be detected
  - signal adds to the background noise

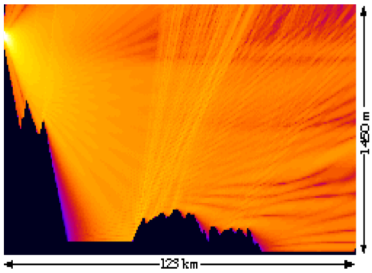


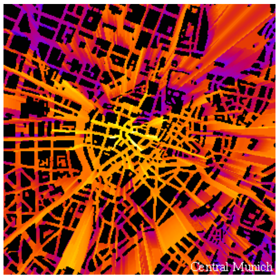
Other Propagation Effects

- **Shadowing**
- **Reflection** at large obstacles
- **Refraction** depending on the density of a medium
- **Scattering** at small obstacles
- **Diffraction** at edges

Real World Examples

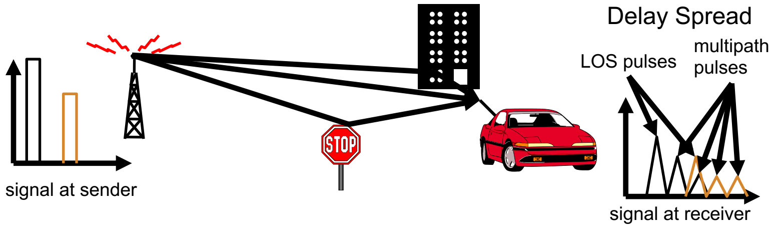






Multipath propagation

- Signal can take **many different paths** between sender and receiver due to reflection, scattering, diffraction



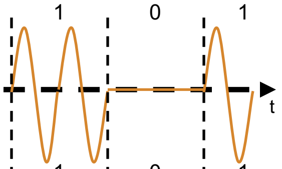
- Time dispersion: signal is dispersed over time
  - interference with "neighbor" symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

Physical Layer: Modulation

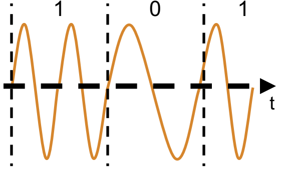
- Digital modulation
  - **digital data is translated into an analog signal**
- Basic schemes
  - **Amplitude Modulation (AM)**
  - **Frequency Modulation (FM)**
  - **Phase Modulation (PM)**

Digital Modulation

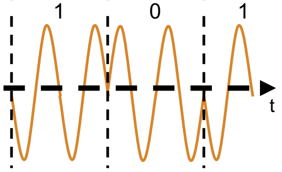
- Modulation of digital signals known as Shift Keying
- **Amplitude Shift Keying (ASK):**
  - very simple
  - low bandwidth requirements
  - very susceptible to interference



- **Frequency Shift Keying (FSK):**
  - needs larger bandwidth

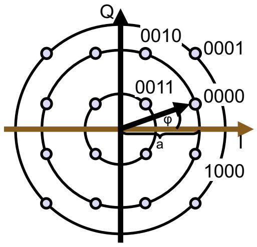


- **Phase Shift Keying (PSK):**
  - more complex
  - robust against interference



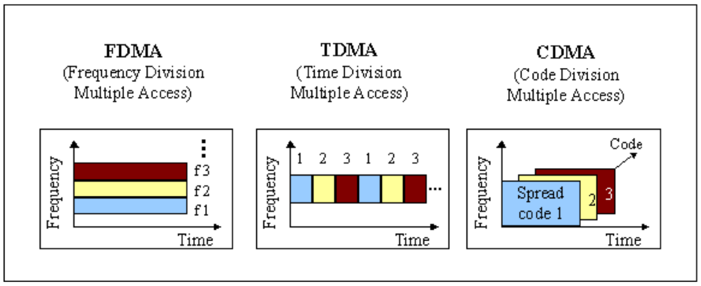
Quadrature Amplitude Modulation

- **Quadrature Amplitude Modulation (QAM)**
  - combines amplitude and phase modulation
  - it is possible to code n bits using one symbol
  - 2^n discrete levels, n=2 identical to QPSK
- Bit error rate increases with n, but less errors compared to comparable PSK schemes
  - Example: 16-QAM (4 bits = 1 symbol)
  - Symbols 0011 and 0001 have the same phase φ, but different amplitude a. 0000 and 1000 have different phase, but same amplitude.



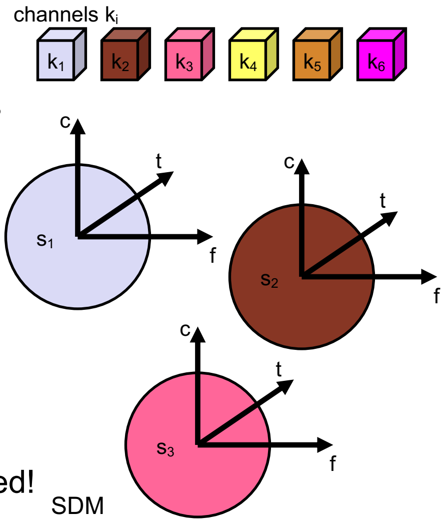
Data Link Layer (Layer 2)

- **Defines when/how medium will be accessed for transmission**
- Units typically called "frames"; error detection/correction; divided into sublayers, including: **MAC = Medium Access Control** (MAC address 6f:00:2b:23:1f:32)
- Cell phone example:



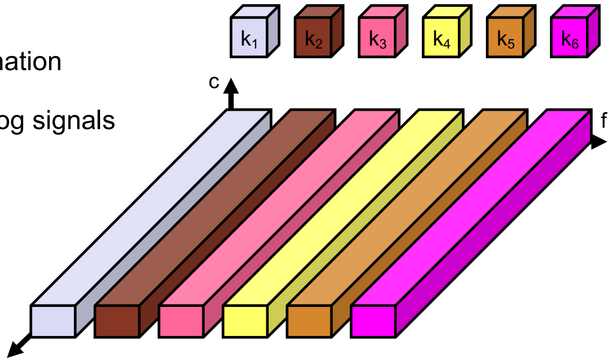
Multiplexing

- **Multiplexing in 4 dimensions**
  - **space (s_i)**
  - **time (t)**
  - **frequency (f)**
  - **code (c)**
- Goal: multiple use of a shared medium
- Important: guard spaces needed!



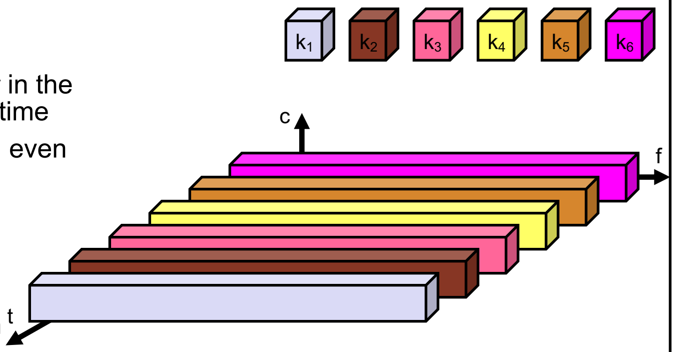
Frequency division multiplexing (FDM)

- Separation of the whole spectrum into **smaller frequency bands**
- A channel gets a certain band of the spectrum for the whole time
- Advantages
  - no dynamic coordination necessary
  - works also for analog signals
- Disadvantages
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible



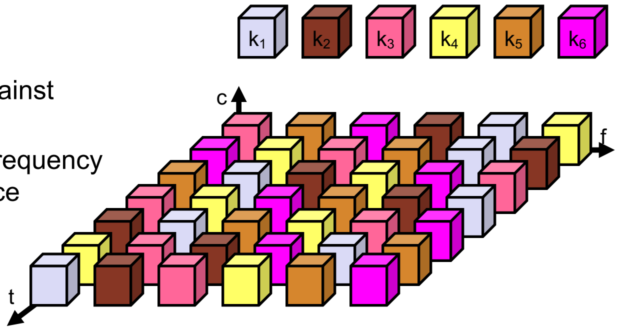
Time division multiplexing (TDM)

- A channel gets the whole spectrum for a **certain amount of time**
- Advantages
  - only one carrier in the medium at any time
  - throughput high even for many users
- Disadvantages
  - precise synchronization necessary



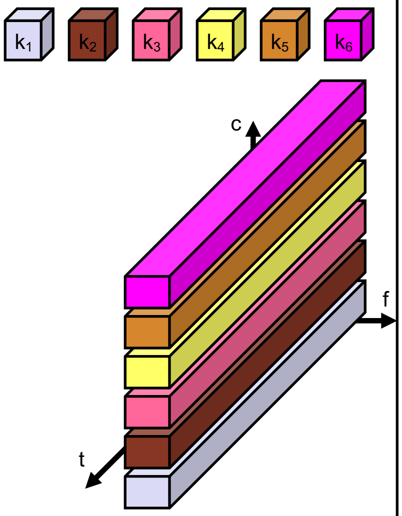
Time and Frequency Multiplex

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time
- Example: **GSM**
- Advantages
  - better protection against tapping
  - protection against frequency selective interference
- But: precise coordination required



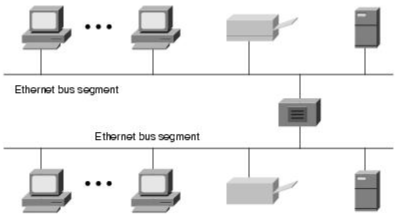
Code Division Multiplexing (CDM)

- Each channel has **unique code**
- All channels use the same spectrum at the same time
- Advantages
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages
  - varying user data rates
  - more complex signal regeneration
- Implemented using spread spectrum technology



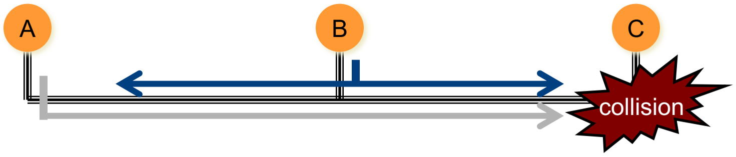
Example: Ethernet (802.3)

- Most popular LAN technology, uses bus architecture
- Easy to install, inexpensive
- Data is broken into **packets**

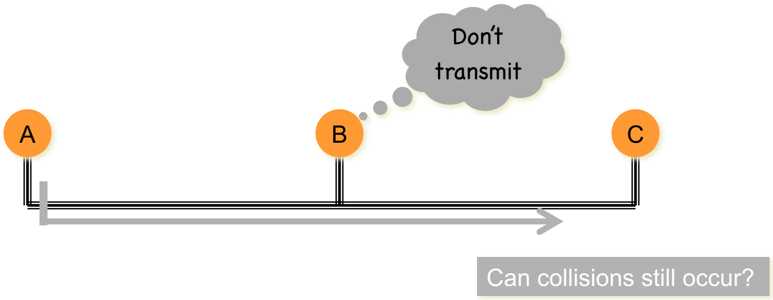


Example: Ethernet

- Medium Access Control (MAC) protocol
- **CSMA/CD** Protocol
  - **C**arrier **S**ense
  - **M**ultiple **A**ccess
  - **C**ollision **D**etection



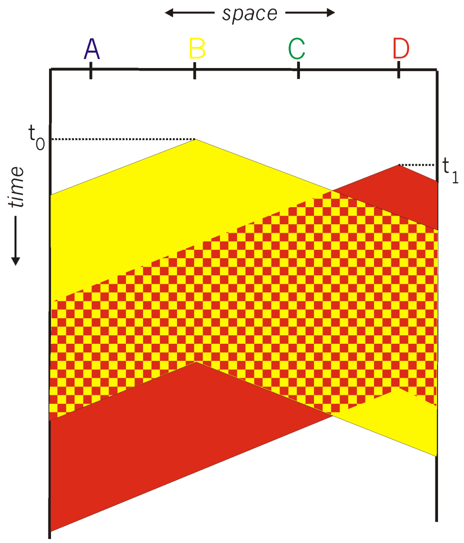
Example: Ethernet



Can collisions still occur?

- "Sense" (listen) carrier ("is anyone else talking right now?")
- If "busy": wait; if "idle": transmit
- CD: Keep listening while transmitting
  - If collision detected: retry at a later time

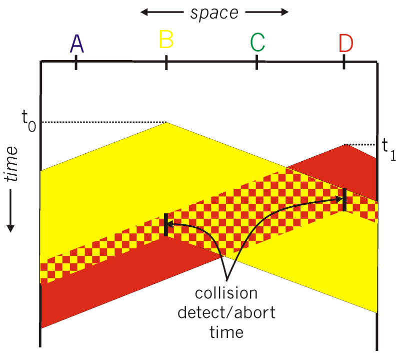
Collisions in CSMA



- Collisions still do occur:
  - Non-zero propagation delays
  - Partial collision: entire packet lost

CSMA/CD

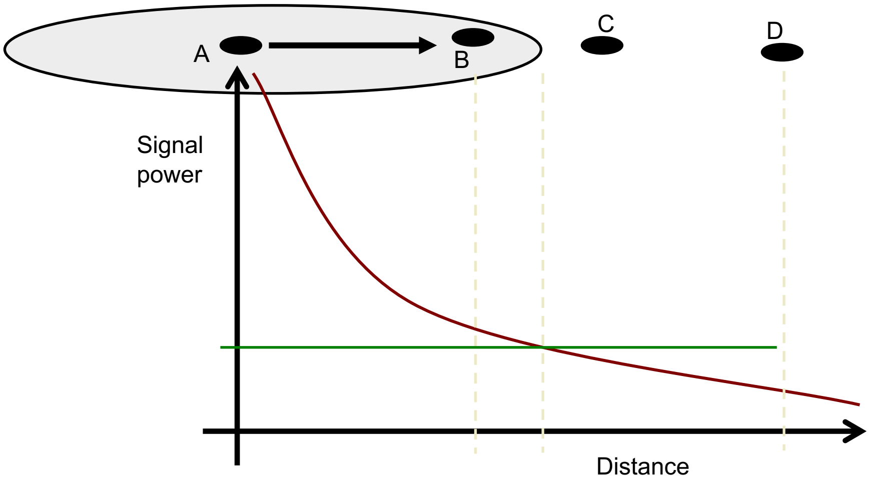
- **CD** = Collision Detection.
- How? Keep listening to channel while transmitting!
- If transmitted signal and sensed signal differ:
  - Collision detected
  - Abort transmission
  - Jam channel: send random bit sequence to “inform” other computers that a collision has occurred



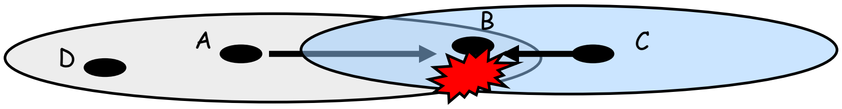
CSMA/CD

- Assumption: the received and transmitted signal are identical (non-dispersive)
- Assumption: receiver "sees" the same signals as transmitters on channel
- **Problem: both not true in wireless networks!**
- Transmitter does not know what the receiver "sees" and therefore does not know if transmission was successful

Wireless Transmissions

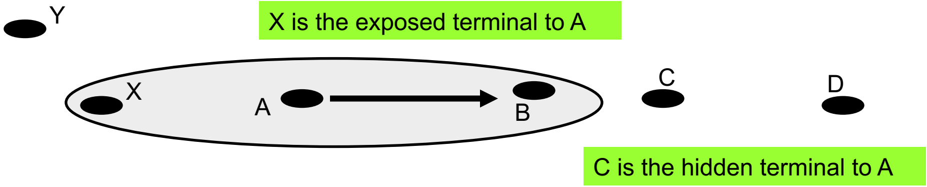


Collision Detection



- Signal received depends on “signal to interference plus noise ratio” (SINR = P/(I+N)).

Hidden Terminal/Exposed Terminal



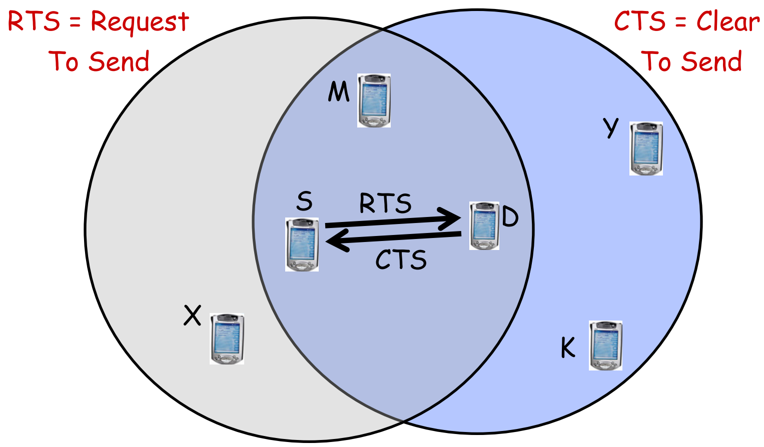
X is the exposed terminal to A

C is the hidden terminal to A

- Hidden terminal: C does not hear A (and A cannot hear C), but it can interfere with A at B.
  - Node SHOULD NOT transmit!
- Exposed terminal: X hears A and wants to transmit to Y. It cannot interfere with A at B.
  - Node SHOULD transmit!

IEEE 802.11 (CSMA/CA)

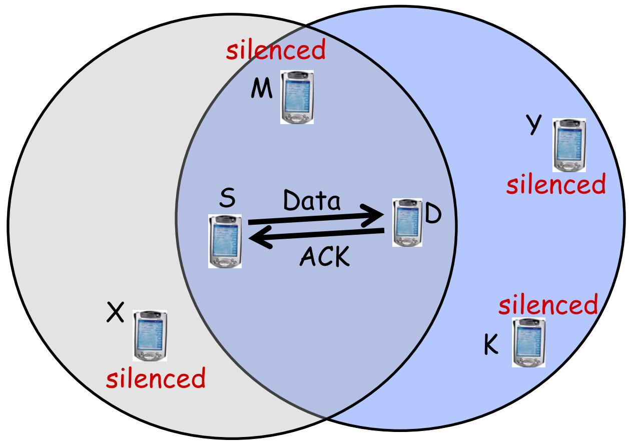
CA = Collision Avoidance



RTS = Request To Send

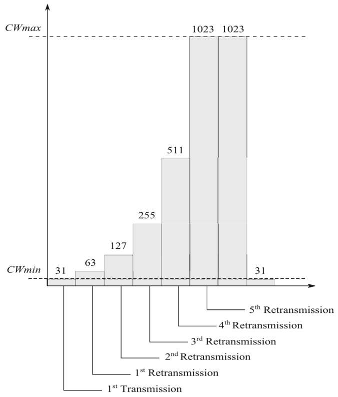
CTS = Clear To Send

IEEE 802.11



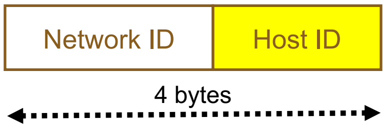
Exponential Backoff

- Wait random amount of time before transmitting!
- Choose a random number R = rand (0, CW_min)
- Each node counts down R
  - Continue carrier sensing while counting down
  - Once carrier busy, freeze countdown
- Whoever reaches ZERO transmits RTS
- If collision detected/suspected:
  - Exponential Backoff Ri = rand (0, 2^i * CW_min)
  - Once successful transmission, reset to rand(0, CW_min)



Network Layer (Layer 3)

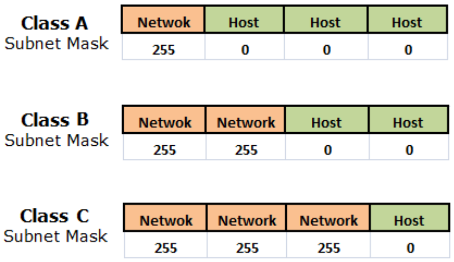
- **Dominant protocol: IP = Internet Protocol**
- Addressing and routing (sender & receiver IP address)
- Uses 32 bit **hierarchical address space** with location information embedded in the structure



- IPv4 address is usually expressed in dotted-decimal notation, e.g.:

128.100.11.56

IPv4



Class A
Subnet Mask

Netwok	Host	Host	Host
255	0	0	0

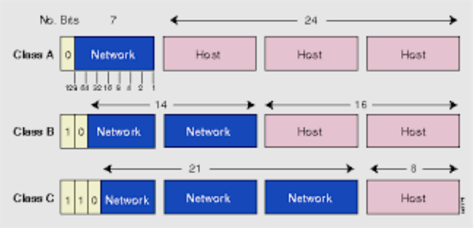
Class B
Subnet Mask

Netwok	Network	Host	Host
255	255	0	0

Class C
Subnet Mask

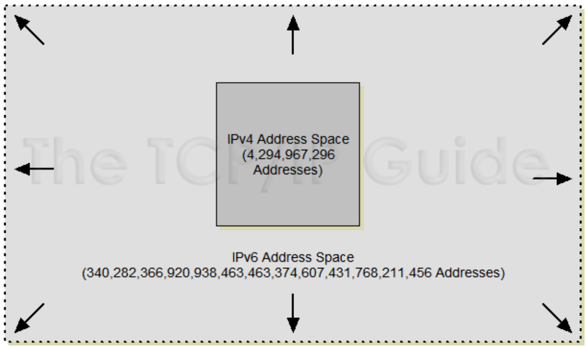
Netwok	Network	Network	Host
255	255	255	0

www.smartPCtricks.com

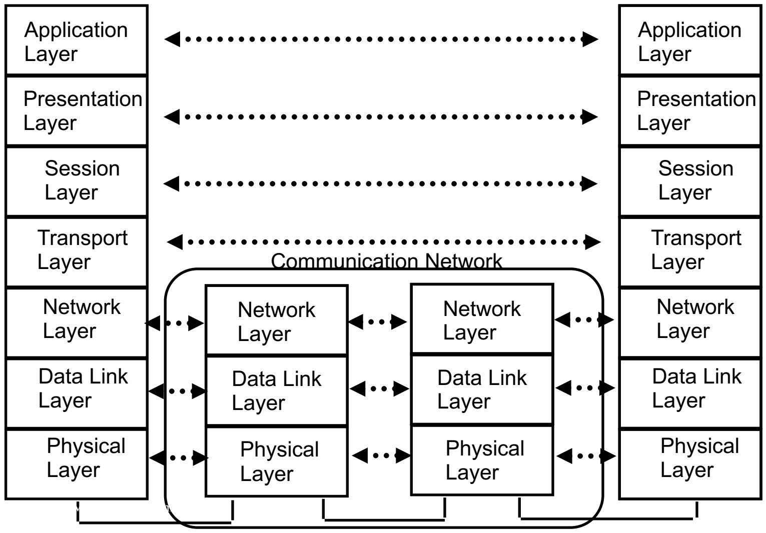


IPv6

- IPv6 addresses are 128 bits long
- 16 bytes of IPv6 address are represented as a group of hexadecimal digits, separated by colons, e.g.:
  2000:fdb8:0000:0000:0001:00ab:853c:39a1
- Shorthand – leave out groups of zeros and leading zeros:
  2000:fdb8:::1:ab:853c:39a1



Network Protocols (“Protocol Stack”)



Application Layer

Presentation Layer

Session Layer

Transport Layer

Network Layer

Data Link Layer

Physical Layer

Communication Network

Network Layer

Data Link Layer

Physical Layer

Network Layer

Data Link Layer

Physical Layer

Application Layer

Presentation Layer

Session Layer

Transport Layer

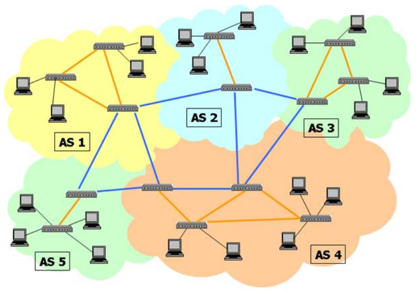
Network Layer

Data Link Layer

Physical Layer

Routers

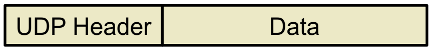
- Form backbone of the Internet
- Use IP layer to identify source and destination of packets
- Look up **routing tables** that determines **“next hop”**



Destination	Next Hop
147.39.21.X	131.19.18.121
89.44.X.X	131.19.22.119
203.21.X.X	137.18.47.48

Transport Layer (Layer 4)

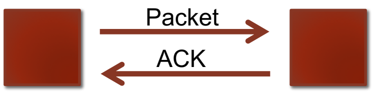
- **UDP** (User Datagram Protocol)



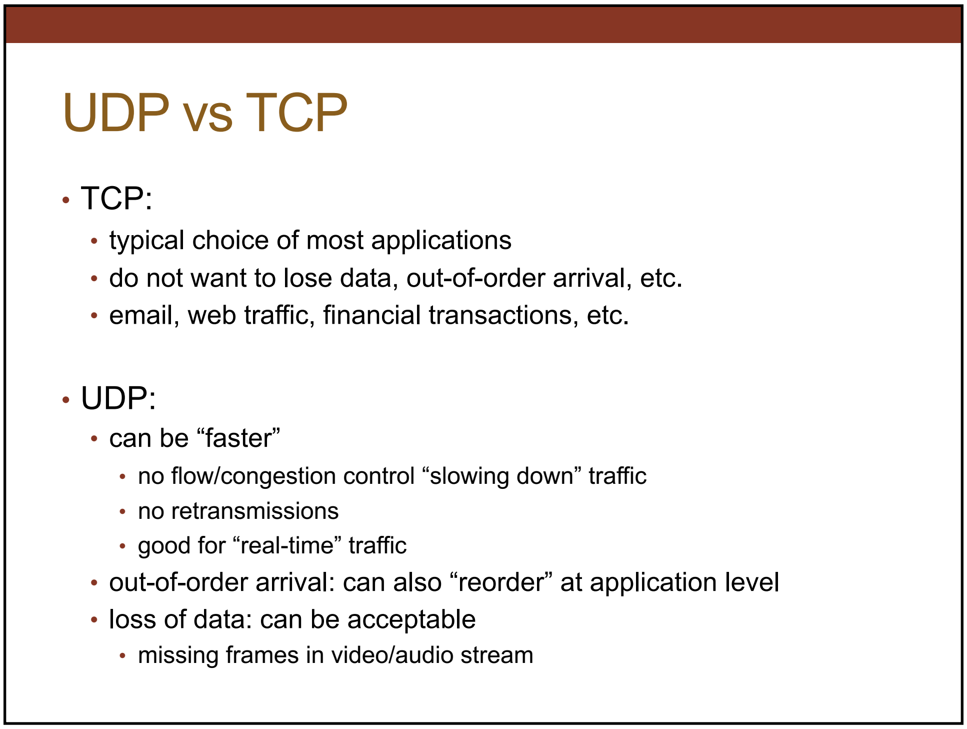
- Adds more addressing: “**ports**”
  - IP address tell you which computer
  - Ports tell you which application on that computer
  - Example: a web server “listens” to requests on port 80
  - Web browser: http://www.google.com:80 = http://216.58.216.100:80
    - “:80": optional
  - **Unreliable!**
    - Packets can get lost; packets can arrive out of order

Transport Layer

- **TCP** (Transmission Control Protocol)
- **Reliable** protocol!
- Adds ports (just like UDP), but also provides:
  - In-order delivery of packets (using sequence numbers)
  - Reliable delivery: using acknowledgment (ACK) packets

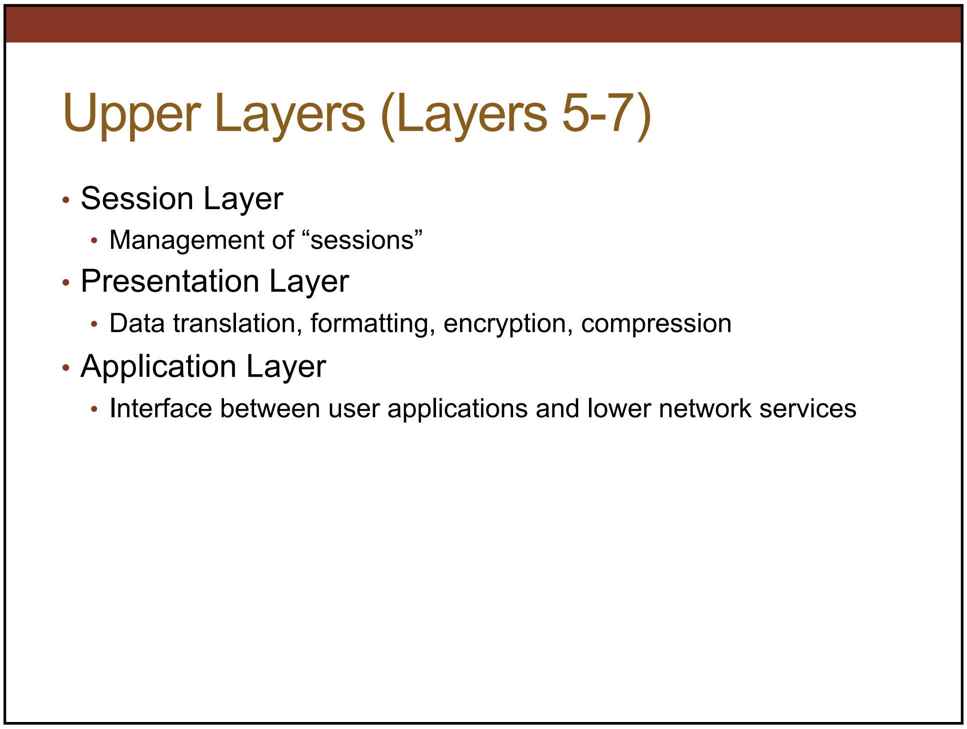


  - **Flow control & congestion control:**
    - Allows receiver to slow down sender
    - Allows “network” to slow down sender



UDP vs TCP

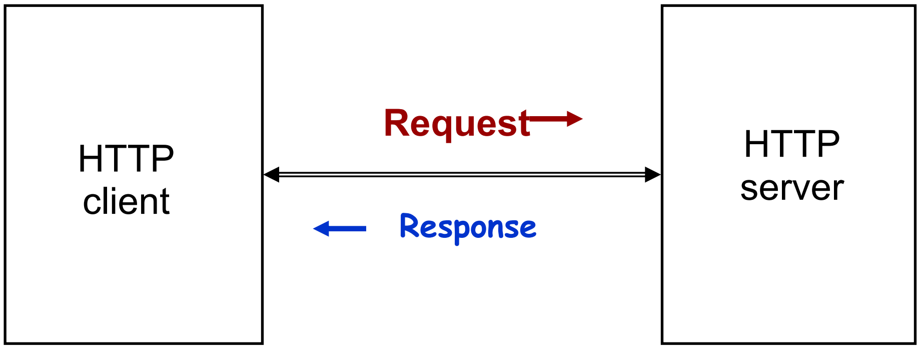
- TCP:
  - typical choice of most applications
  - do not want to lose data, out-of-order arrival, etc.
  - email, web traffic, financial transactions, etc.
- UDP:
  - can be "faster"
    - no flow/congestion control "slowing down" traffic
    - no retransmissions
    - good for "real-time" traffic
  - out-of-order arrival: can also "reorder" at application level
  - loss of data: can be acceptable
    - missing frames in video/audio stream



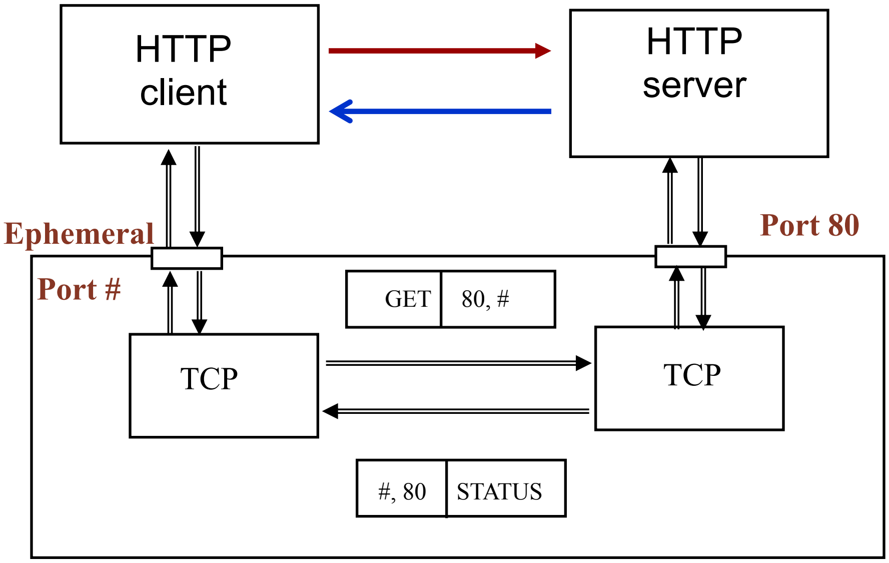
Upper Layers (Layers 5-7)

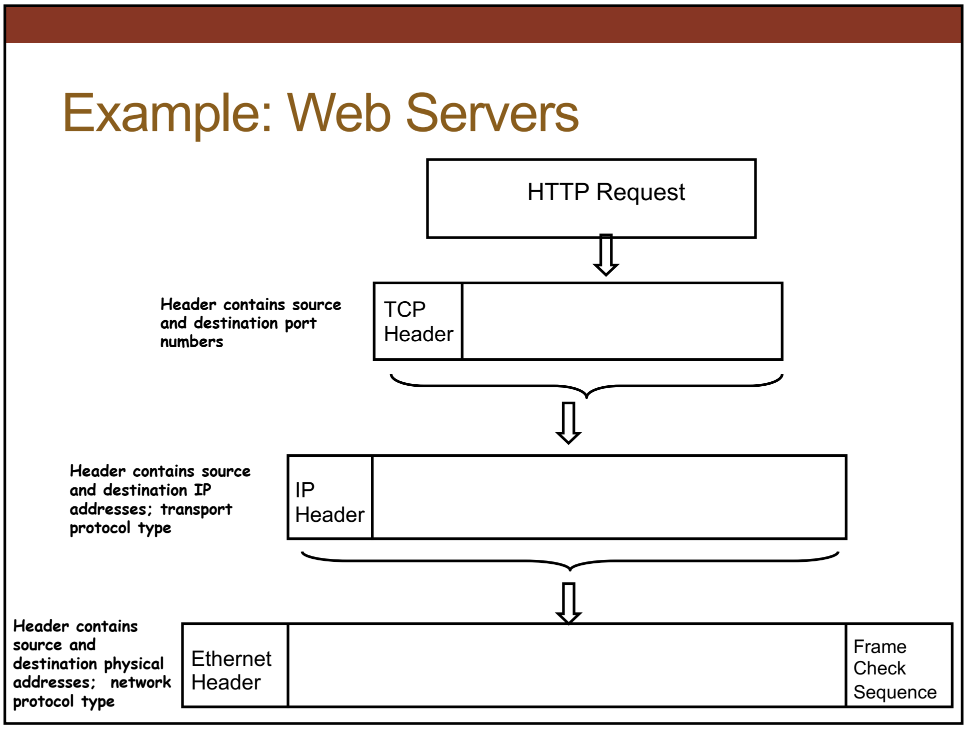
- Session Layer
  - Management of "sessions"
- Presentation Layer
  - Data translation, formatting, encryption, compression
- Application Layer
  - Interface between user applications and lower network services

Example: Web Servers



Example: Web Servers





Example: Web Servers

HTTP Request

Header contains source and destination port numbers

TCP Header

Header contains source and destination IP addresses; transport protocol type

IP Header

Header contains source and destination physical addresses; network protocol type

Ethernet Header

Frame Check Sequence