Computer Network Design

Introduction

Yalda Edalat – Spring 23

Focus of the Course

Main Points of The Course

1. To learn how the Internet works
   - What really happens when you browse the web?
   - What are TCP/IP, DNS, HTTP, NAT, 802.11, ...?

2. To learn the fundamentals of computer networks
   - What hard problems must they solve?
   - What design strategies have proven valuable?

Computer Networks

- Computer networks:
  - A collection of autonomous computers interconnected by a single technology
  - Example: Internet

Uses of Computer Networks

- Example Uses of Networks:
  - Work:
    - Email, file sharing, printing, …
  - Home:
    - Movies / songs, news, calls / video, e-commerce,…
  - Mobile:
    - Maps, games, videos, information access, calls / texts,…

Uses of Computer Networks (2)

- Why We Need Networks? For User Communications

  - Voice-over-ip
  - Video conferencing
  - Instant messaging
  - Social networking

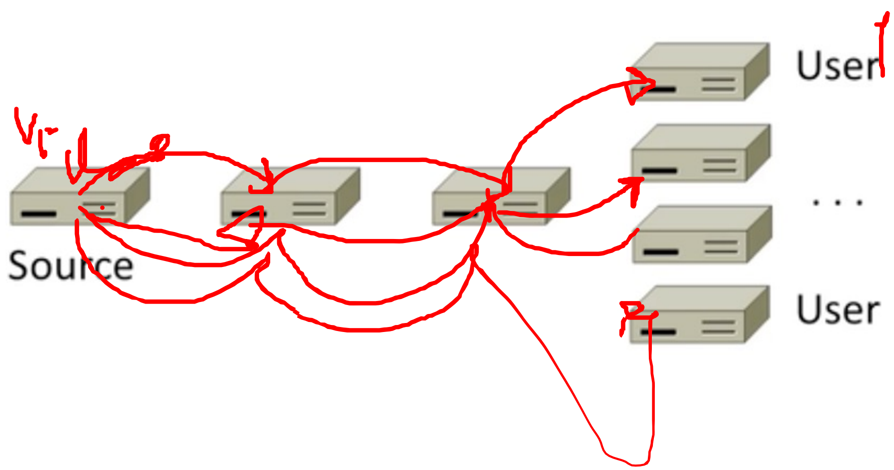
➢Need low latency for interactivity

Uses of Computer Networks (3)

- Why We Need Networks? For Resource Sharing
  - Many users may access the same underlying resources
    - E.g., 3D printer, search index, machines in the cloud
  - More cost effective than dedicated resources per user
    - Even network links are shared!

Uses of Computer Networks (4)

- Why We Need Networks? For Content Delivery
  - Content is delivered to users
    - Videos, songs, apps and upgrades, web pages
    - Using "replica" is more efficient than sending a copy all the way to each user



3x4=12

6 hops

Uses of Computer Networks (5)

- Why We Need Networks? For Computer Communication
  - To let computers interact with other computers
    - E.g., e-commerce, reservations
    - Enables automated information processing across different parties

Uses of Computer Networks (6)

- Why We Need Networks? For Connecting Computers to physical World
    - For gathering sensor data, and for manipulating the world
        - E.g., webcams, location on mobile phones, door locks,…

Example Networks

- Can be categorized by:
  - Technology
  - Purpose (Scale)

Example Networks by Technology

- WiFi (802.11)
- Enterprise/Ethernet
- ISP (Internet Service Provider)
- Cable / DSL
- Mobile phone / Cellular (2G, 3G, 4G)
- Bluetooth
- Telephone
- Satellite….

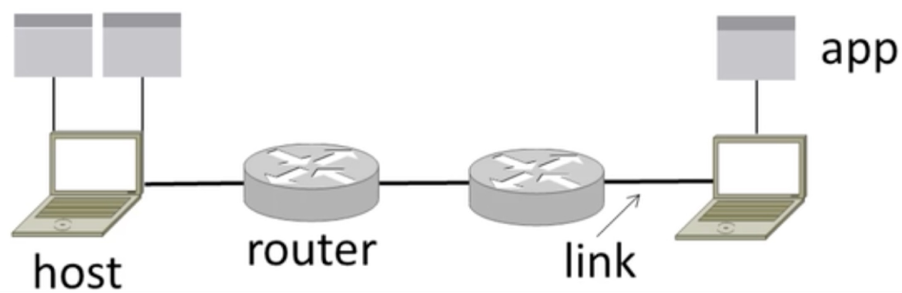
Example Networks by Scale

- PAN (Personal Area Network)
- LAN (Local Area Network)
- MAN (Metropolitan Area Network)
- WAN (Wide Area Network)
- The Internet (network of all networks)

Network Components

- Parts of a network:

Component	Function	Example
Application, or app, user	Uses the network	Skype, iTunes, Amazon
Host, or end-system, edge device, node, source, sink	Supports apps	Laptop, mobile, desktop
Router, or switch, node, hub, intermediate system	Relays messages between links	Access point, cable/DSL modem
Link, or channel	Connects nodes	Wires, wireless



Networks Need Modularity

- Networks do lots of thing for applications:
  - Make and break connections
  - Find a path through the network
  - Transfer information reliably
  - Sends as fast as the network allows
  - Shares bandwidth among users
  - Secure information in transit
  - Let many hosts to be added
  - …..

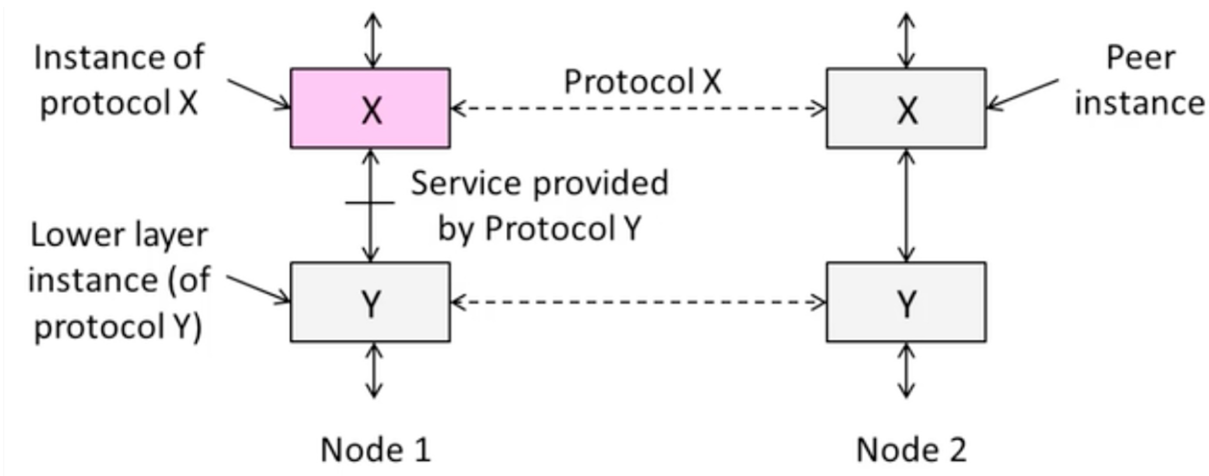
➢There is a need for a form of modularity to manage complexity and support reuse

Protocols and Layers

- **Protocols** and **layering** are the main structuring methods used to divide up network functionality
- Each instant of a protocol talks virtually to its peer using protocol
- Each instance of a protocol uses only the services of the lower layer

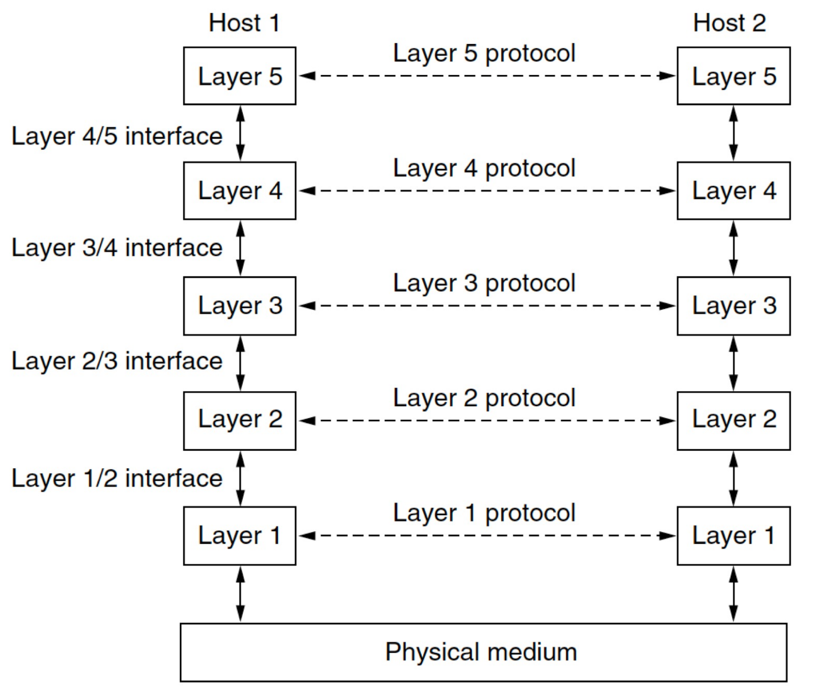
Protocols and Layers (2)

- Protocols are horizontal and layers are vertical



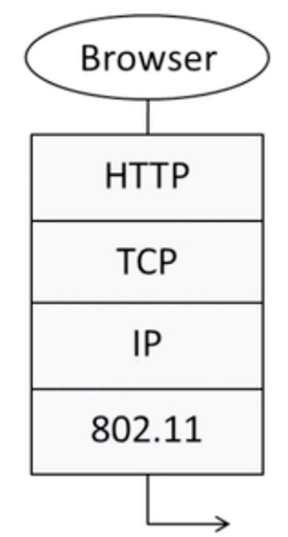
Protocols and Layers (3)

- Set of protocols in use is called a protocol stack



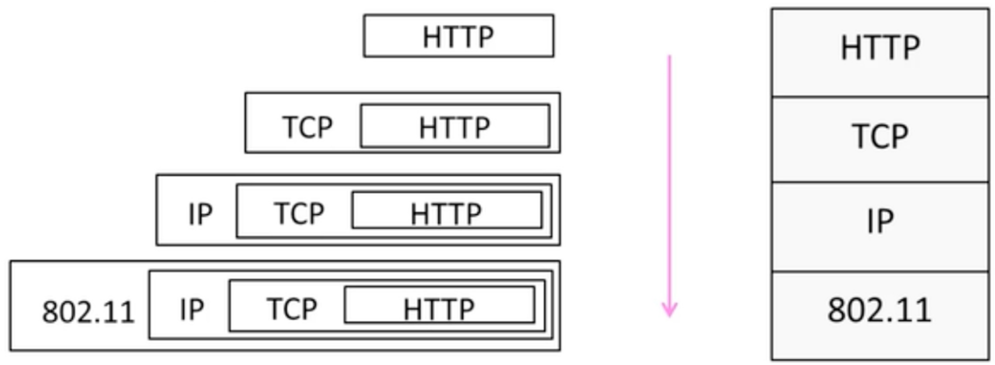
Protocols and Layers (4)

- Protocols you have probably heard of:
  - TCP, 802.11, HTTP,…
- An example protocol stack:
  - Used by a web browser on a host that is wirelessly connected to the Internet



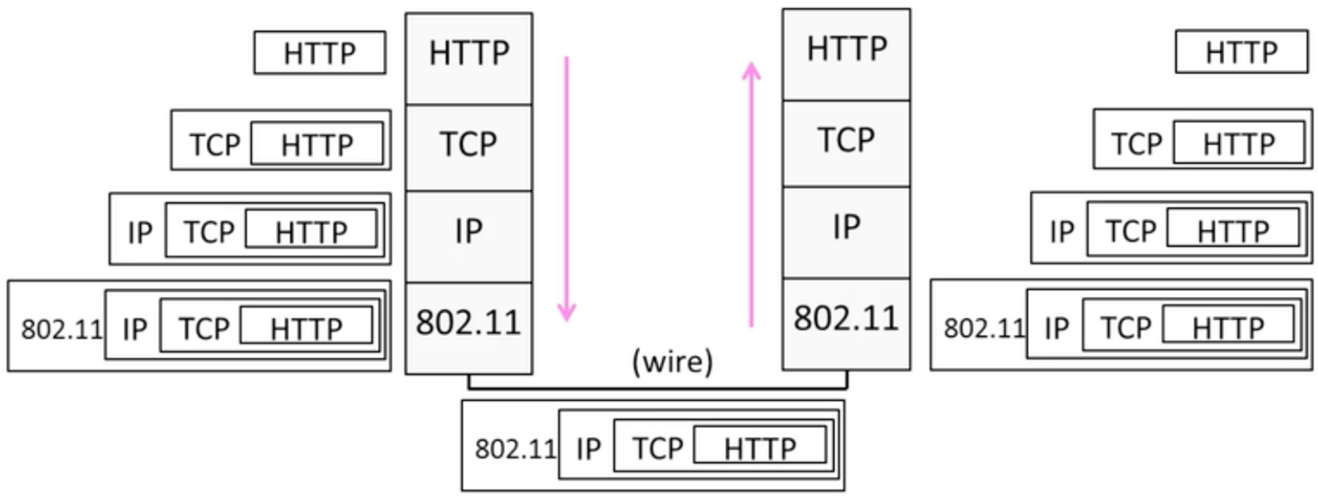
Encapsulation

- Lower layers wrap higher layers’ content by adding their own information to make a new message
  - Each layer adds its own header
  - Example: Sending letter



Decapsulation

- The process of opening up encapsulated data is decapsulation
- Message "on the wire" looks like an onion
  - Lower layers are outermost



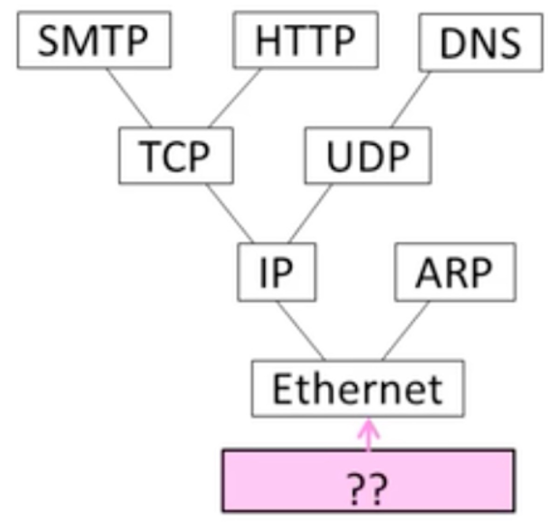
Multiplexing

- Combining data from several sources into single stream so it can be separated later
- Can occur at different layers
- **Protocol Multiplexing** allows multiple different protocols to co-exist on the same layer

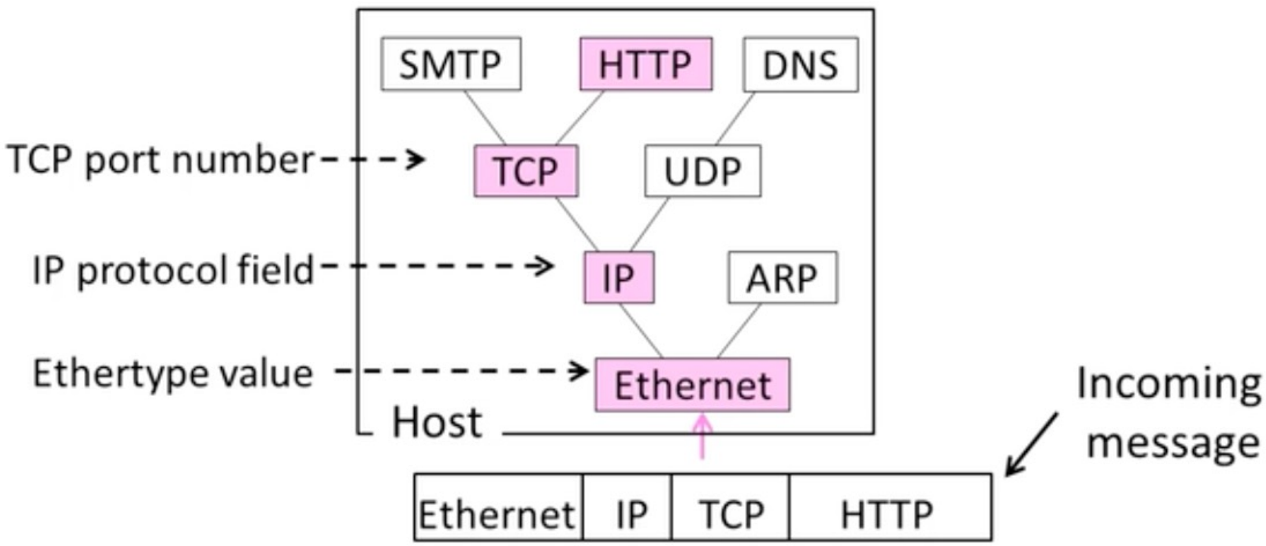
Demultiplexing

- Technique to separate from common input into several outputs
  - Incoming PDU is de-multiplexed, using control information and sent to upper layer

- Incoming message must be passed to the protocol that it uses



Demultiplexing Example



Reference Models

- What functionality should be implemented at which layer?
- It is a key design question
- Reference models provide frameworks that guide us
- Two reference models:
  - OSI model
  - TCP/IP model

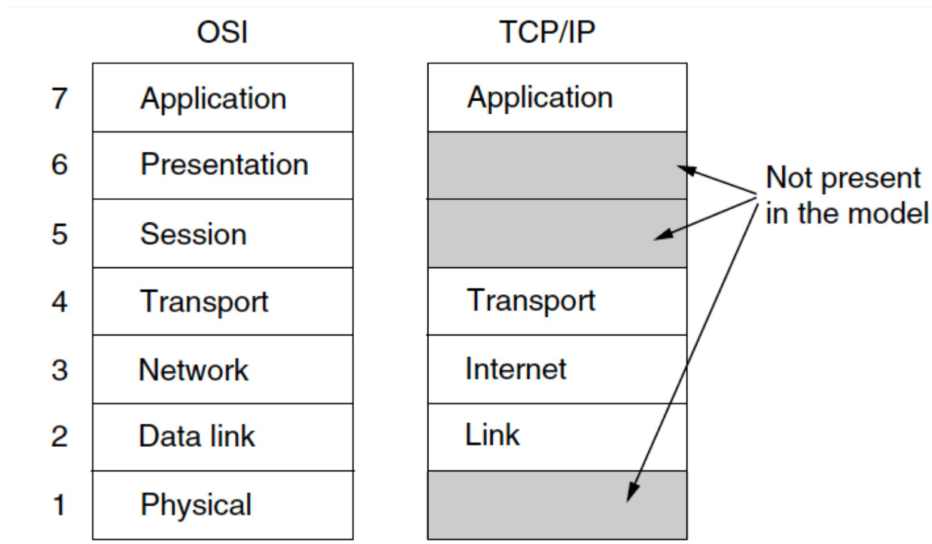
Reference Models

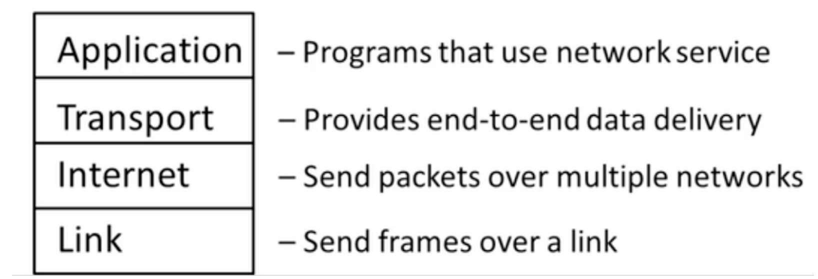
- OSI model:
  - International standard to connect devices
  - 7 layers
  - Not used in practice

7	Application	– Provides functions needed by users
6	Presentation	– Converts different representations
5	Session	– Manages task dialogs
4	Transport	– Provides end-to-end delivery
3	Network	– Sends packets over multiple links
2	Data link	– Sends frames of information
1	Physical	– Sends bits as signals

Reference Models

- TCP/IP Reference Model:
  - Four layer model which is based on the experience



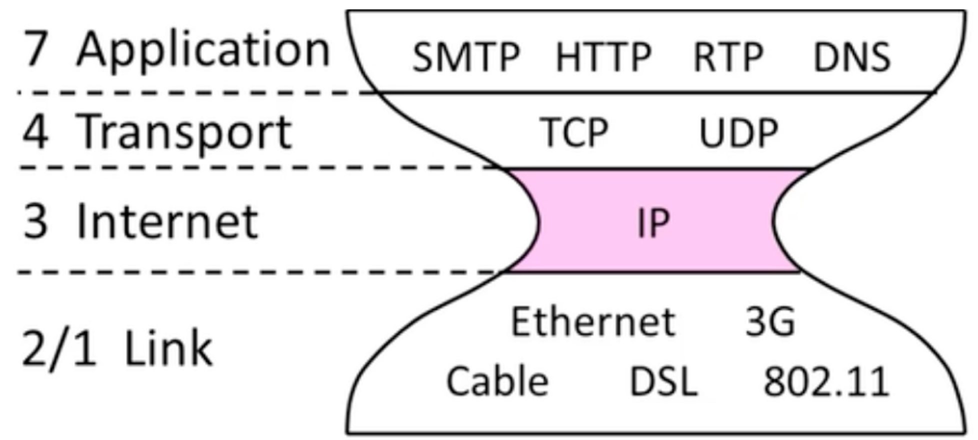


This Course’s Reference Model

7	Application	– Programs that use network service
4	Transport	– Provides end-to-end data delivery
3	Network	– Send packets over multiple networks
2	Link	– Send frames over one or more links
1	Physical	– Send bits using signals

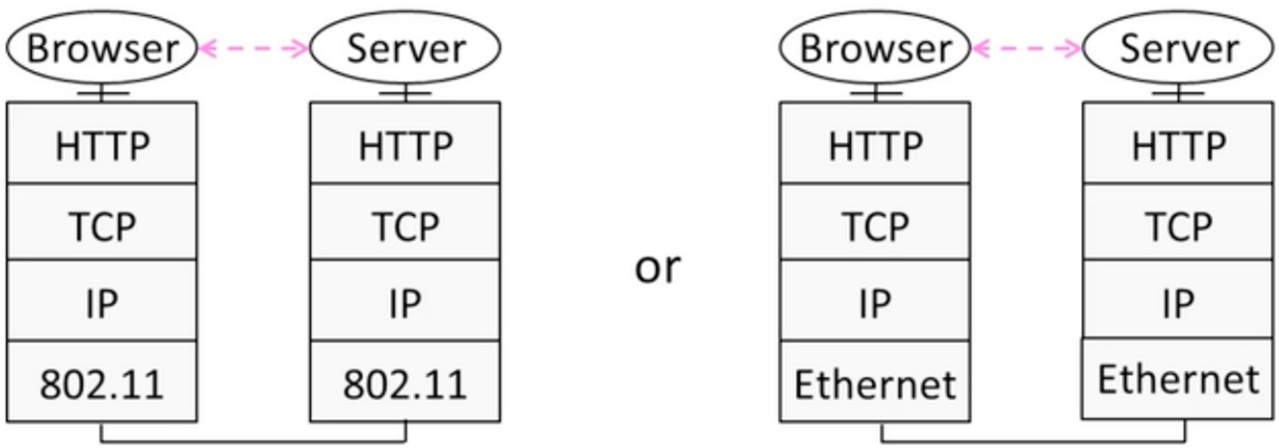
Protocols (TCP/IP Model)

- IP is the "narrow waist" of the Internet
  - Supports many links below and apps above



Advantage of Layering

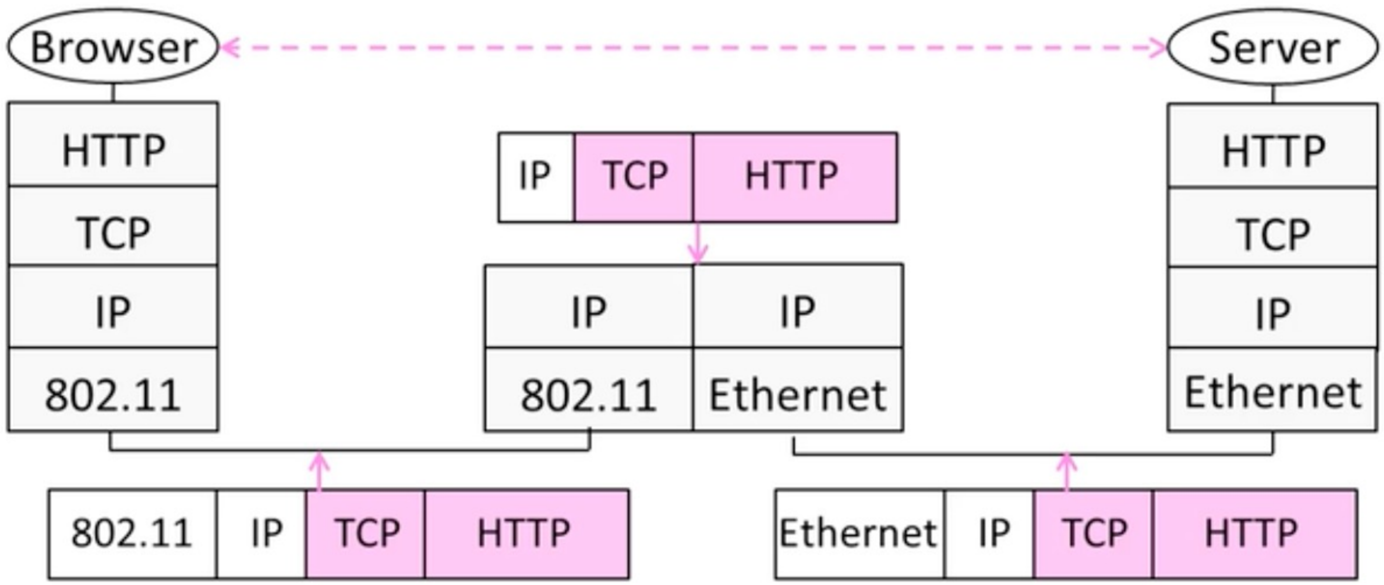
- Information hiding and resuse



Advantage of Layering (2)

- Using information hiding to connect different systems

Advantage of Layering (3)

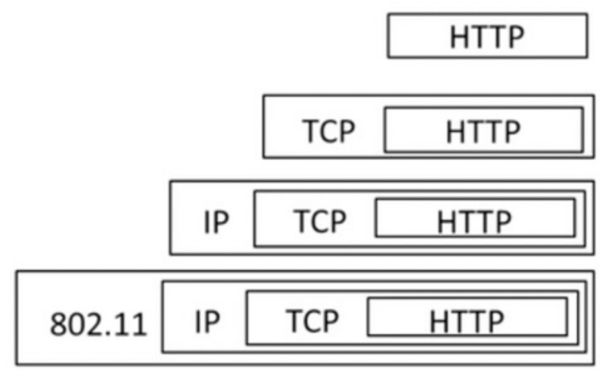


Disadvantage of Layering

- Adds overhead
  - But minor for long messages
- Hides information
  - App might care whether it is running over wired or wireless!

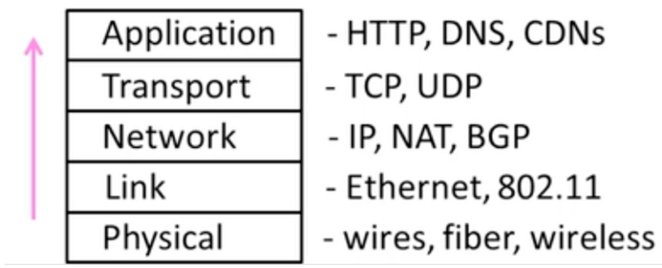
Protocol Data Unit (PDU)

Layer	PDU
Application	Message (Data)
Transport	Segment
Network	Packet
Link	Frame
Physical	Bit



Course Agenda

- Bottom-up through the layers

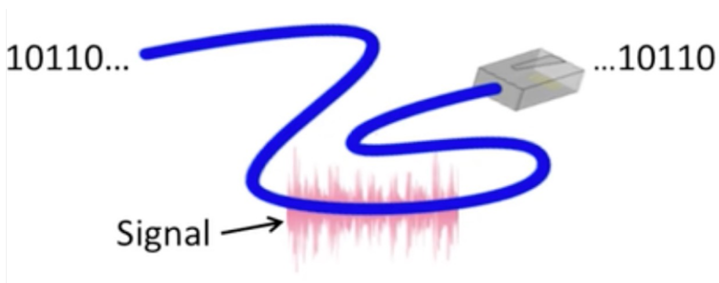


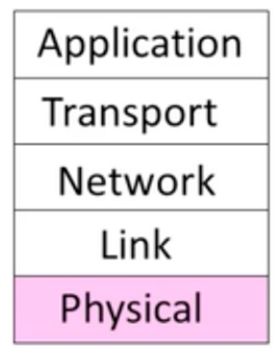
- Followed by some detail on
  - Security

Physical Layer

Physical Layer Overview

- Concerns how signals are used to transfer message bits over a link
  - Wires etc. carry analog signals
  - We want to send digital bits





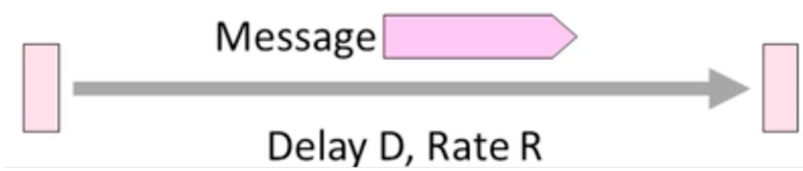
Types of Links

- Based on direction:
  - Full-duplex
    - Bidirectional
  - Half-duplex
    - Bidirectional
  - Simplex
    - Unidirectional

- Based on Media:
  - Wired -> can send directly
  - Wireless -> send broadcastly

Simple Link Model

- Key parameters:
  - Rate (or bandwidth, capacity, speed) in bit/second
  - Delay in seconds, related to length



- Other important properties:
  - Whether the channel is broadcast, error rate,…

Message Latency

- **Latency** is the delay to send a message over a link

  - **Transmission delay:** time to put M-bit message on the wire
    T-delay = M (bits) / Rate (bits/sec) = M/R seconds

  - **Propagation delay:** time for bits to propagate across the wire
    P-delay = Length / speed of signals = length / (2/3) C = D seconds

  - Combining two terms we have: **L = M/R + D**

Metric Unit

- The main prefixes we use:

Prefix	Exp.	prefix	exp.
K(ilo)	10^3	m(illi)	10^{-3}
M(ega)	10^6	μ(micro)	10^{-6}
G(iga)	10^9	n(ano)	10^{-9}

- Use power of 10 for rates, ex: 1 Mbps = 10^6 bps
- Use power of 2 for storage, ex: 1 KB = 2^{10} bytes
- "B" is for bytes and "b" is for bits

Latency Example

- "Dialup" with telephone modem:

  $D = 5$ ms, $R = 56$ Kbps, $M = 1250$ bytes

  $L = ((1250 \times 8) / 56 \times 10^3) + 5 \text{ ms} = 184 \text{ ms}$

- Broadband cross-country link:

  $D = 50$ ms, $R = 10$ Mbps, $M = 1250$ bytes

  $L = ((1250 \times 8) / 10 \times 10^6) + 50 \text{ ms} = 51 \text{ ms}$

- A long link or a slow rate means high latency

Bandwidth-Delay Product

- Messages take space on the wire!
- A measurement of how many bits (bytes) can fill up a network link

$$BD = R \times D$$

- Ex: Fiber at home, cross country

  R=40 Mbps, D=50 ms

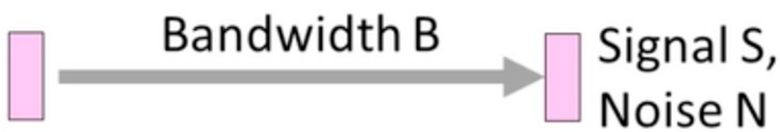
$BD = 40 \times 10^{6} \times 50 \times 10^{-3}$ bits

$= 2000$ Kbits

$= 250$ KB

Key Channel Properties

- The bandwidth (B), signal strength (S) and noise strength (N)
  - B limits the rate of transitions
  - S and N limit how many signal levels we can distinguish



Shannon Capacity

- Shannon Capacity (C), tells the maximum data rate or capacity of a noisy channel whose bandwidth is B Hz and whose signal-to-noise ratio is S/N

$$\boxed{C = B \log_2(1 + S/N) \text{ bits/sec}}$$

- Shannon capacity shows that it is possible to send information reliably over the channel up to this capacity but not more

Wire/Wireless Perspective

- Wires and fibers:
  - Engineer link to have requisite SNR and B
  - ➢Can fix data rate

Engineer SNR for data rate

- Wireless:
  - Given B, but SNR varies greatly
  - ➢Can not design for worst case, must adapt data rate

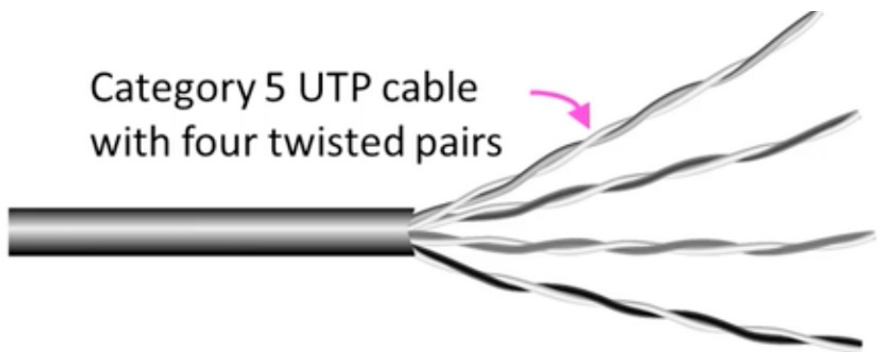
Adapt data rate to SNR

Medias

- Media propagate signals that carry bits of information
- Media groups:
  - Guided
    - Wires
    - Fibers (Fiber optic cable)
  - Unguided
    - Wireless

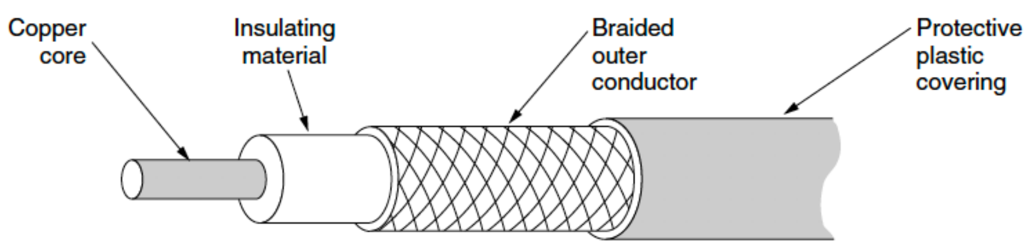
Wires (Twisted Pair)

- Very common; used in LANs and telephone lines
  - Twists reduce radiated signal



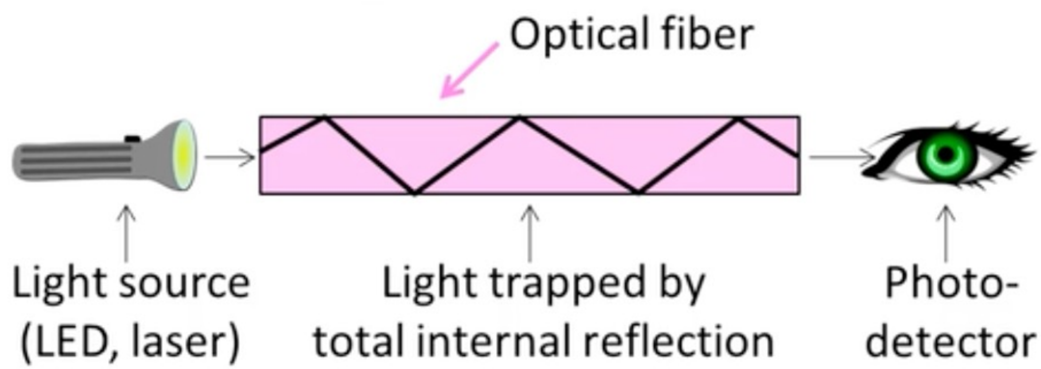
Wires (Coaxial Cable)

- Also common
- Better shielding for better performance



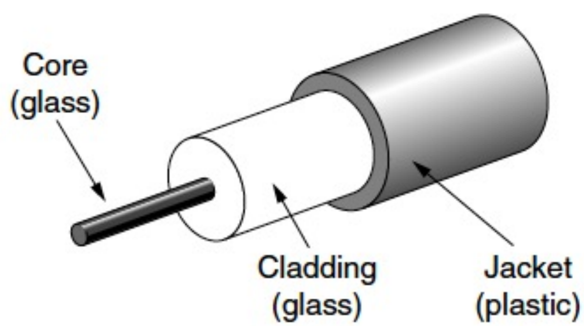
Fiber

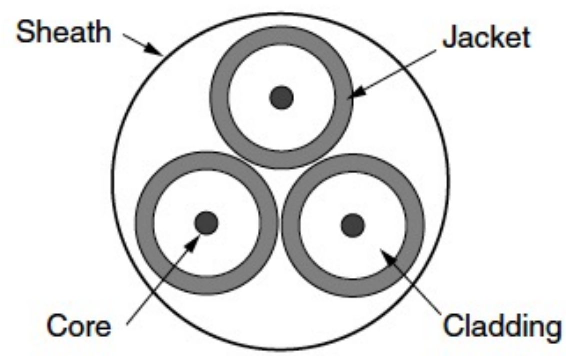
- Long, thin, pure strands of glass
  - Enormous bandwidth (high speed) over long distance



Fiber

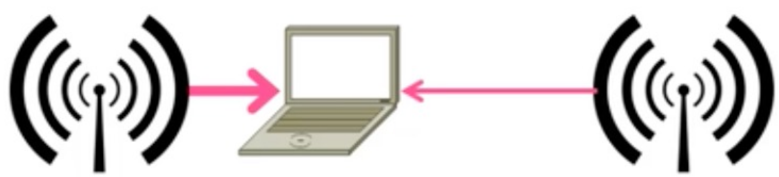
- Two varieties: multi-mode (shorter links, cheaper) and single-mode (up to ~100 km)





Wireless

- Sender radiates signal over a region
  - Message is broadcast
  - Received by all nodes in the range
  - In many directions, unlike a wire
  - Nearby signals (same frequency) **interfere** at the receiver; need to coordinate use



To-do List

- Assignments:
  - Prepare for a short quiz
  - Make sure you install lockdown browser
  - Sign the academic integrity form (due next week)
- Other:
  - Post your research topic on discussion thread (due on Feb 9th)