Week 2 – Physical Layer

COMP90007
Internet Technologies

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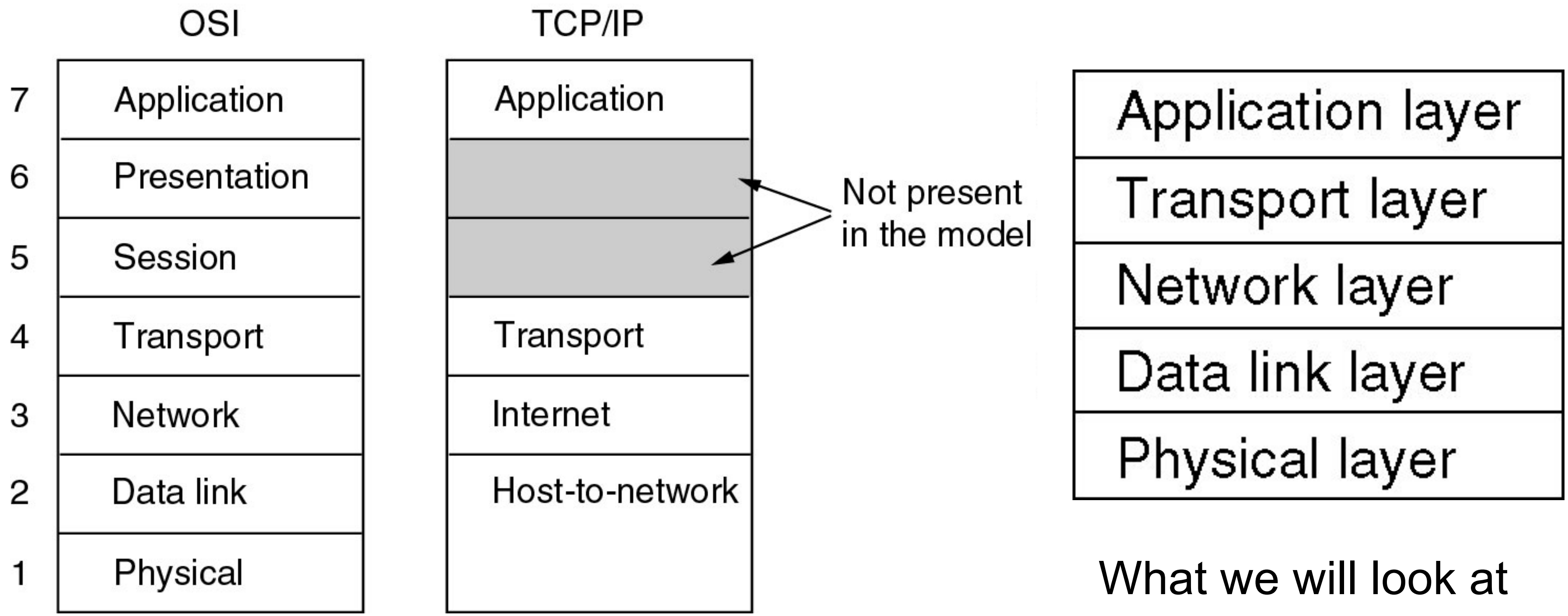
Review



What we will look at

Outline

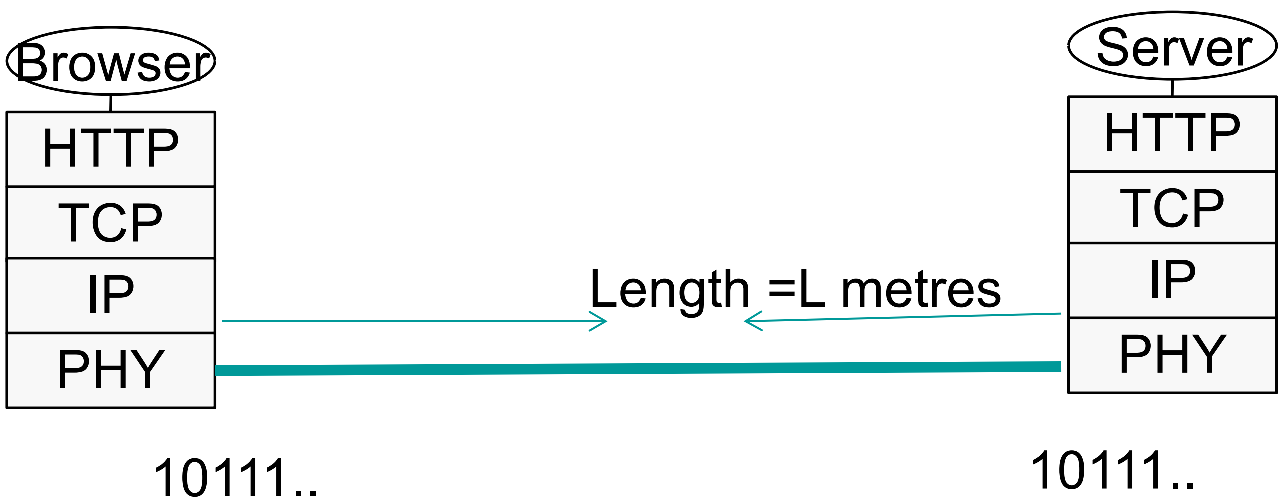
- The service
  - Link Model
  - Bandwidth and delay
- Guided and Unguided Transmission Media
  - Twisted Pair
  - Coax
  - Fibre Optics
  - Wireless Transmission
- Multiplexing
- Digital Modulation and information theory

What is the Physical Layer ?

- Recall the layer hierarchy from network reference models
  - The physical layer is the lowest Layer in OSI model
  - The physical layer's properties in TCP/IP model are in the "host-to-network" division.
- The physical layer is concerned with the mechanical, electrical and timing interfaces of the network
- Various physical media can be used to transmit data, but all of them are affected by a range of physical properties and hence have distinct differences
- How many different types of physical media can you think of?

Link Model

- Simplified Link Model: Consider the network as a connected link between computers
- We can abstract the physical channel as a link



Link Model

- *Bandwidth* is usually treated as rate of transmission in bits/second
- *Delay* (in seconds) is the time required for the first bit to travel from computer A to computer B.

Example

- We need about 1 kbit/sec to transmit voice.
- Bandwidth of single mode fibre can reach 1 Tbit/sec.
- How many voice calls can be transmitted through an Fiber Optic Cable?

$10^{12} / 10^{3}$= 1 billion calls per channel

Tbit/s kbit/s

Message Latency

- Latency is the time delay associated with sending a message over a link
- This is made of up two parts
  - Transmission delay:
    - T-delay = Message in bits / Rate of transmission
    - = M/R seconds
  - Propagation delay
    - P-delay= length of the channel/ speed of signals
    - Length / Speed of signal (2/3 of speed of light for wire)
  - Latency = L = M/R + P-delay

Example -1

- A home computer is connected to an ISP server through 56 K bps modem. Assuming a frame size of 5600 bits, compute P-Delay and T-Delay for the link. Assume speed of signal = 2/3 C and length of the link is 5 K metres.
- T-delay = 5600 (bits)/ 56 000 (kbps) = 100 m sec
- P-delay = 5 (km)/200000 (km/s) = 0.025 m sec
- Latency = 100.025 m sec

Example-2

- Now for the previous question, assume a countrywide optical broadband link of length 1000 kms of bandwidth 100 M bits/sec. Assuming a frame size of 5600 bits, compute P-Delay and T-Delay for the link. Assume speed of signal = C = 300000 km/sec.
- T-delay = 5600 (bits)/ 100 000 000 (bits/s) = 0.056 m sec
- P-delay = 1000 (km) /300000 (km/s) = 3.33 m sec
- Latency = 3.386 m sec

The Bandwidth Revolution?

- Evolutionary steps in available bandwidth:
  - CPU speeds increase by a factor of ~20 per decade
    - 1981: PC 4.77Mhz vs 2001: PC 2 Ghz
- Bandwidth speeds increase by a factor of ~125 per decade (1981: Modem 56kbps vs 2001: Net 1Gbps)
- Current CPU speed now approaching physical limits - constrained by physical properties pertaining to granularity of engraving on silicon
- Current bandwidth available up to 50Tbps - vastly exceeding the rate at which we can convert electrical impulses to optical pulses

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  - Coax
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- Multiplexing
- Digital Modulation and information theory

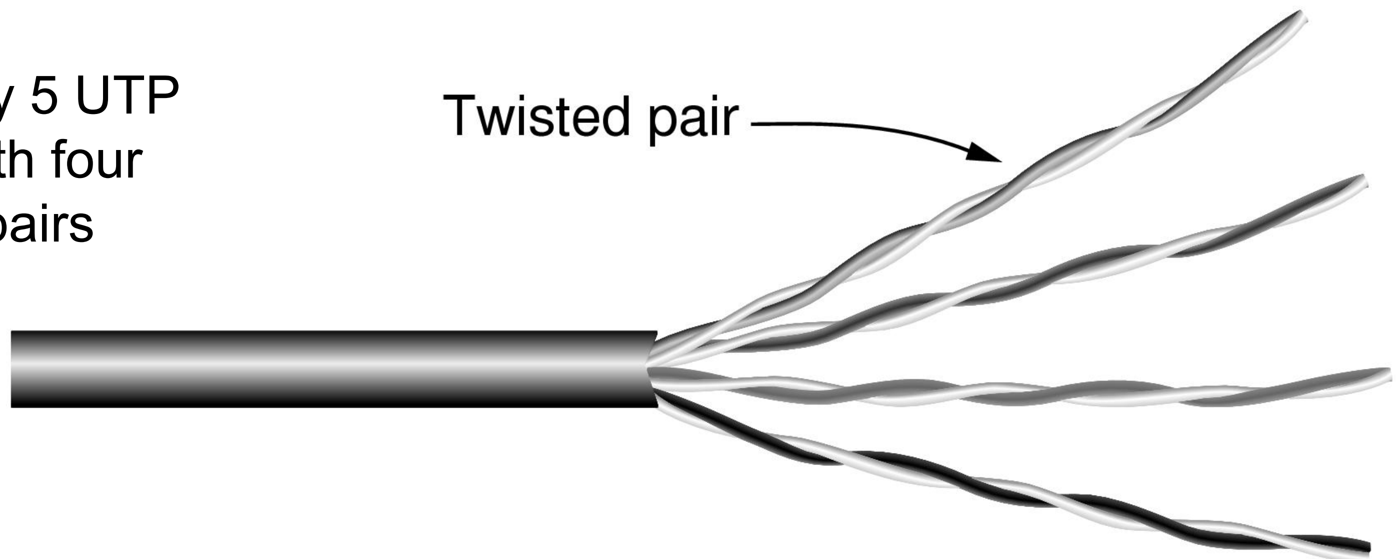
Signal Attenuation

- How far and how much data a medium can carry has a lot to do with signal attenuation:
  - "**Attenuation** is the loss or reduction in the amplitude (strength) of a signal as it passes through a medium."

Wires – Twisted Pair

- Two insulated copper wires, twisted in helical (DNA) form.
- Twisting reduces radiance of waves from effectively parallel antennae
- Distance up to <5km, repeaters can extend this distance (large buildings often have km’s of cabling)
- twisting reduces interference

Category 5 UTP cable with four twisted pairs



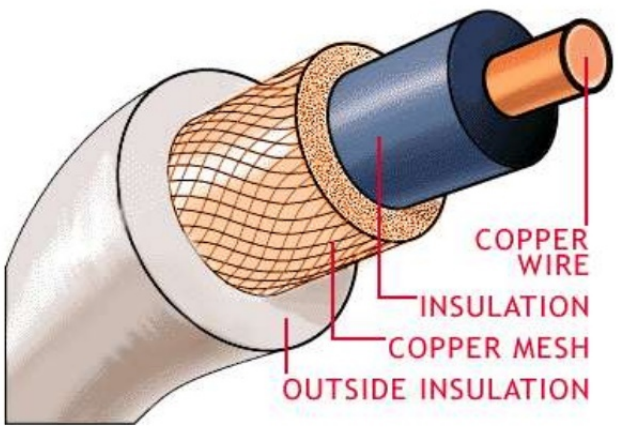
Properties and Types of Twisted Pair

- Bandwidth dependent on distance, wire quality/density
- Cat 3 - 2 wires, 4 pairs in sheath, 16Mhz
- Cat 5 - 2 wires, 4 pair in sheath, more twists = less interference, higher quality over longer distance, 100 Mhz
- Cat 6 - 250 Mhz
- Cat 7 - 600Mhz + ?

Coaxial Cable ("Co-ax")

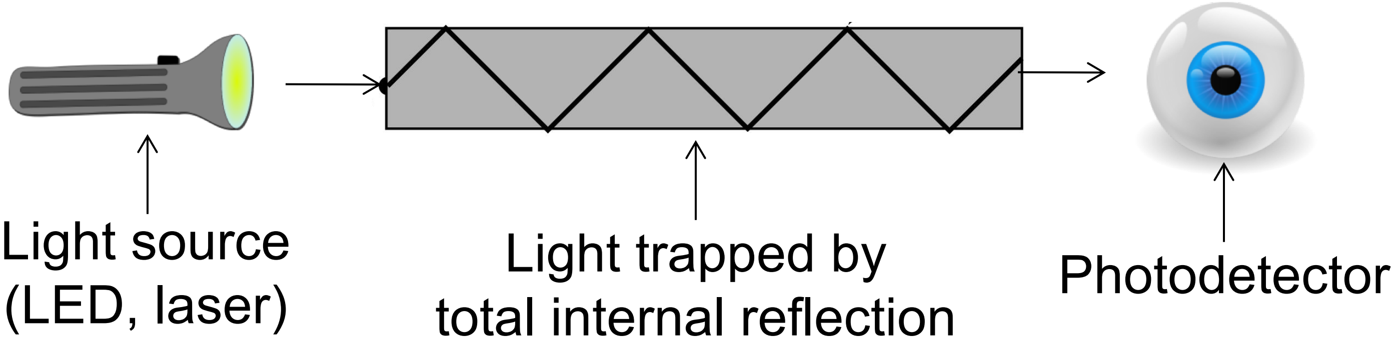
- Better shielding than twisted pair = higher speeds over greater distances
- Copper core with insulation, mesh, and sheath
- Bandwidth approaches 1Ghz
- Still widely used for cable TV/Internet

A diagram of a coaxial cable



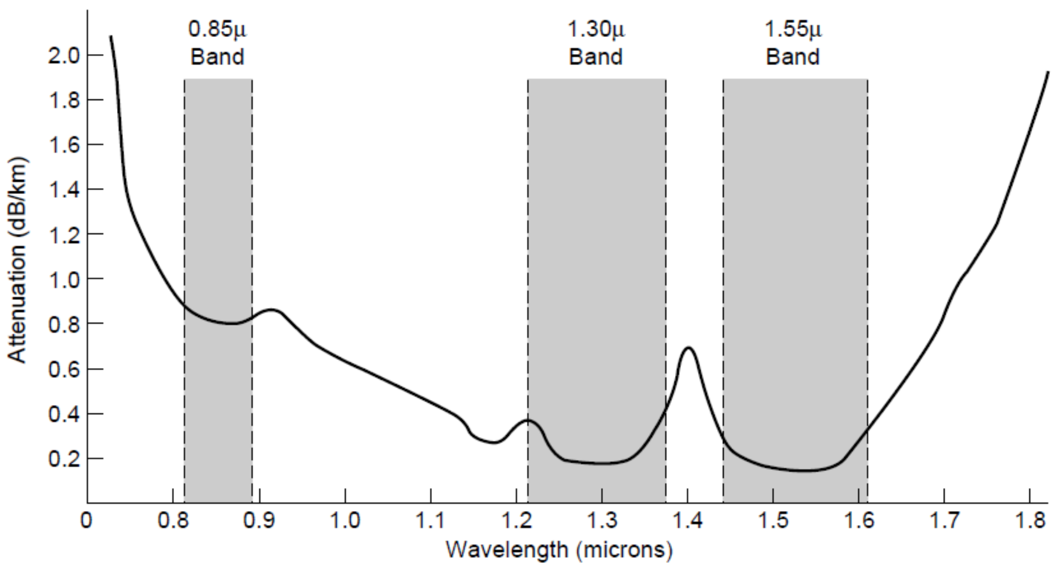
Fiber Optics

- Optical transmission has 3 components: light source, transmission medium, detector
- Semantics: light = 1, no light = 0 (basic binary system)
- Data transmission over a fibre of glass
- A detector generates electrical pulse when light hits it
- Refraction between air/silica boundary is compensated for by design - total internal reflectiondistance ISP links, Fiber-to-the-Home
- Common for high rates and long distances



Transmission of Light Through Fibre

Fiber has enormous bandwidth (THz) and tiny signal loss – hence high rates over long distances



Attennuation (loss per km) of light through glass depends on wavelength of light

Optical communications at 0.85, 1.30, 1.55 microns;

1.30 and 1.55 have low loss <5%/km)

0.85 physical property sharing between laser and electronics

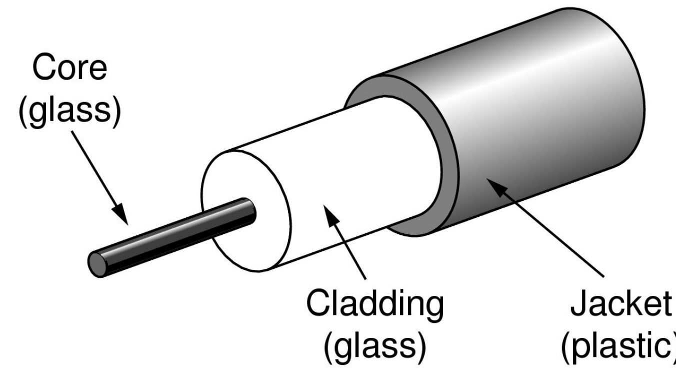
Fiber Optic Cables #1

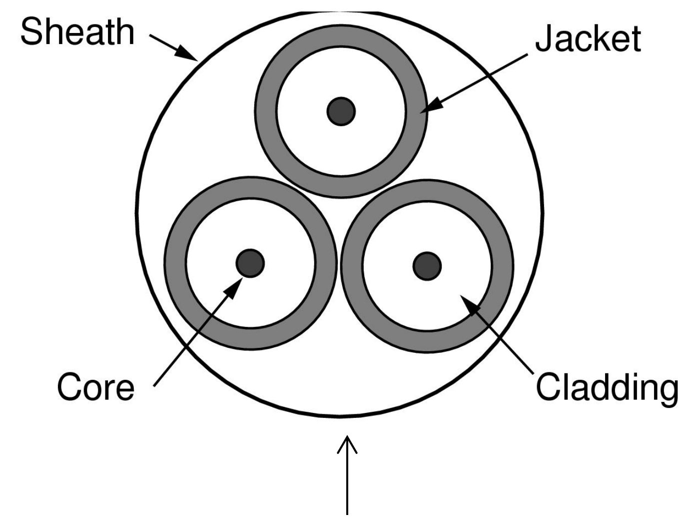
Single-mode

- Core so narrow (10um) light can't even bounce around
- Used with lasers for long distances, e.g., 100km

Multi-mode

- Other main type of fiber
- Light can bounce (50um core)
- Used with LEDs for cheaper, shorter distance links

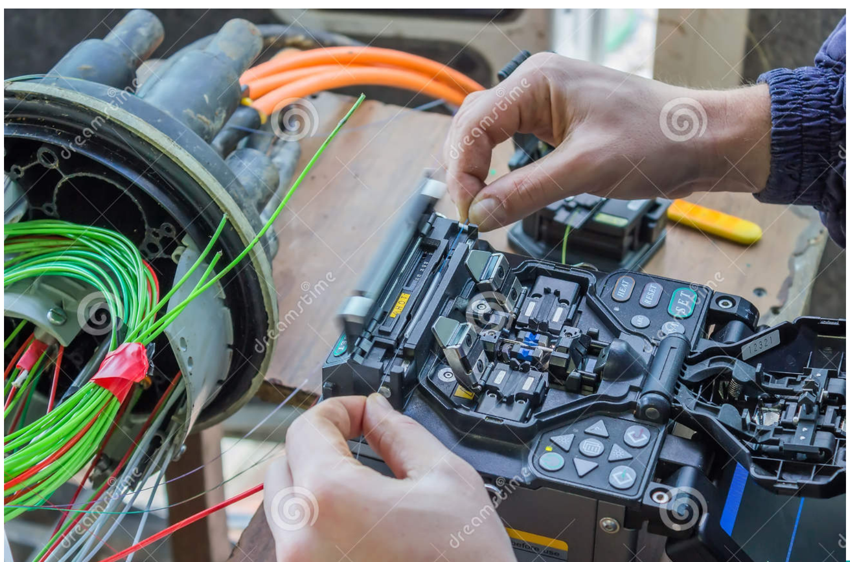


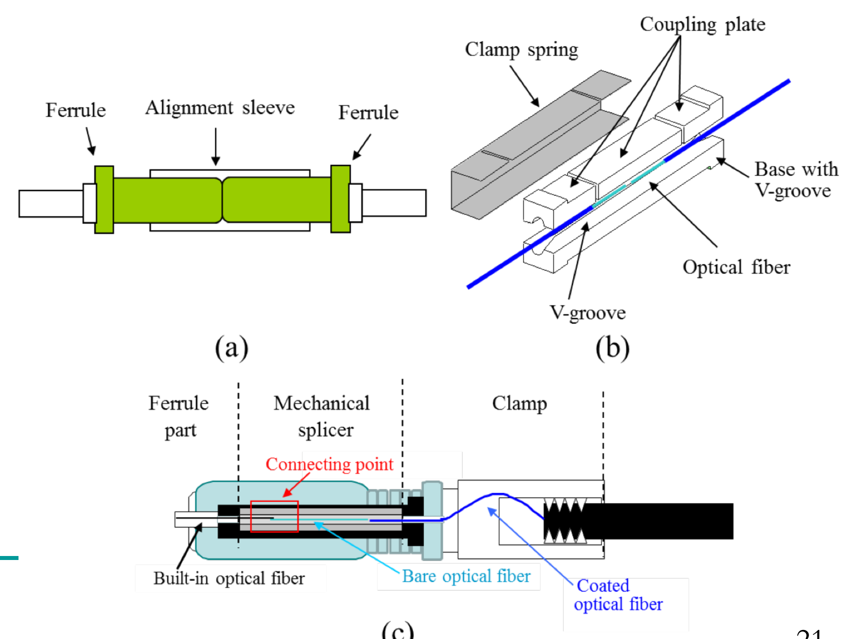


Fibers in a cable

Fiber Optic Connections

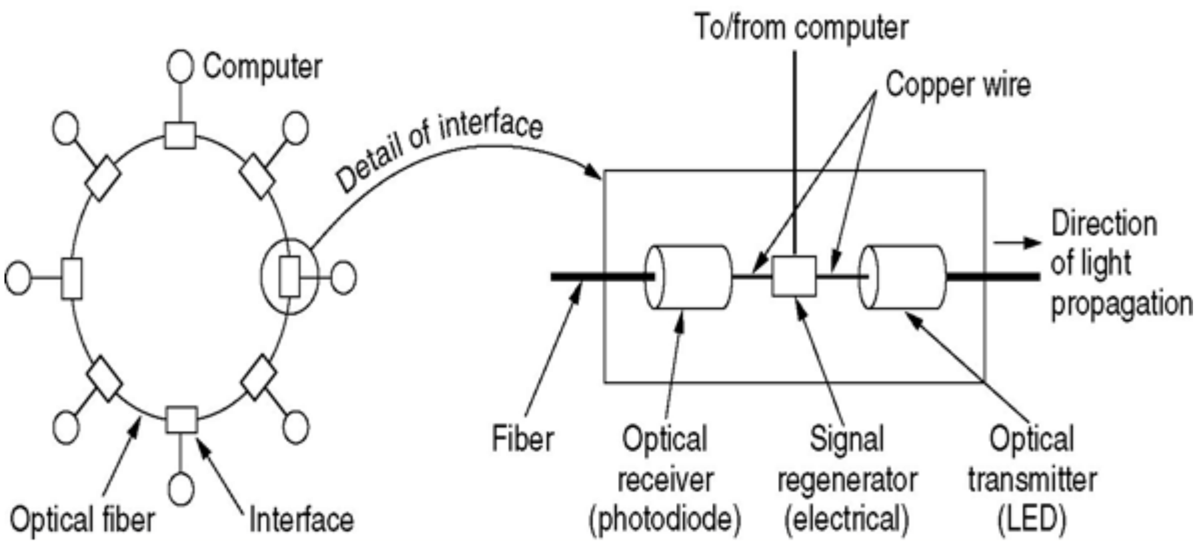
- Connectors and Fiber Sockets (10-20% loss, but easy to configure)
- Mechanical Splice (10% loss, labour intensive)
- Fusion (<1% loss, but specialised)
- Signalling using LED's or semiconductor lasers





Fiber Optic Networks

- Fiber optic cable is a scalable network media - LAN, WAN, long haul
- Fibre optic cable can be considered either as a ring or as a bus network type (series of point to point connections)



Fibre Optic Ring

Comparison: Wires and Fiber

Comparison of the properties of wires and fiber:

Property	**Wires**	**Fiber**
Distance	Short (100s of m)	Long (tens of km)
Bandwidth	Moderate	Very High
Cost	Inexpensive	More Expensive
Convenience	Easy to use	Harder to use
Security	Easy to tap	Hard to tap

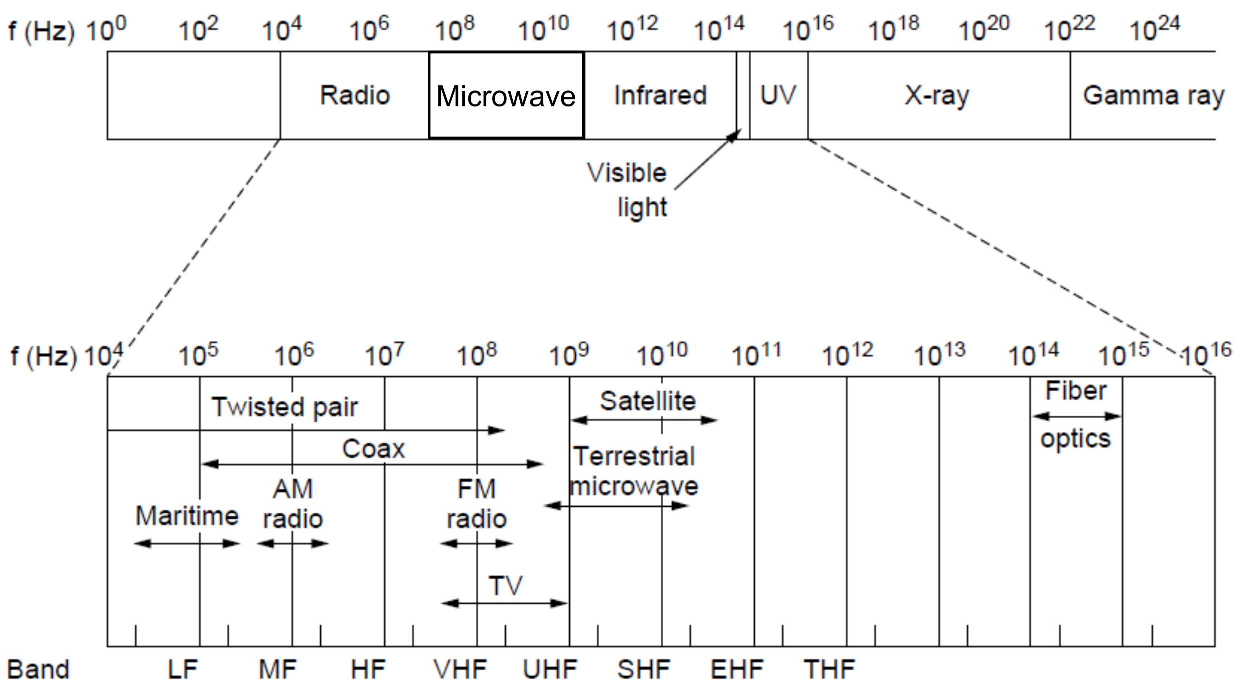
Wireless Transmission

- Mobile users requires a mobility enabled network - contrast with the wired networks
- Wireless networks can provide advantages even in fixed location environments
- There are many types of wireless data transmission networks, but they all have a common basis - radio wave propagation
- Unlike previous mediums wireless signals are broadcasted over a region
- Potential signal collisions – Need regulations

Electromagnetic Spectrum (1)

Different bands have different uses:

- Radio: wide-area broadcast;
- Infrared/Light: line-of-sight
- Microwave: LANs and 3G/4G;



Wireless vs. Wires/Fiber

Wireless:

- \+ Easy and inexpensive to deploy
- \+ Naturally supports mobility
- \+ Naturally supports broadcast
- Transmissions interfere and must be managed
- Signal strengths hence data rates vary greatly

Wires/Fiber:

- \+ Easy to engineer a fixed data rate over point-to-point links
- Can be expensive to deploy, esp. over distances
- Doesn’t readily support mobility or broadcast

Communication Satellites

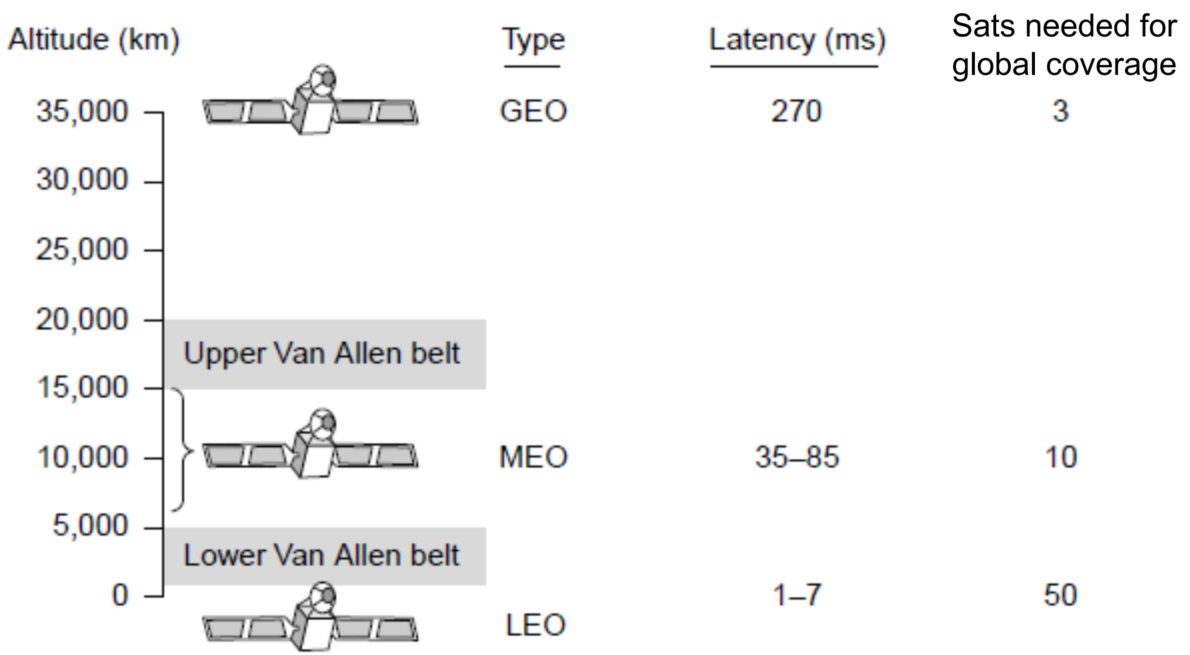
Satellites are effective for broadcast distribution and anywhere/anytime communications

- Kinds of Satellites
- Geostationary (GEO) Satellites
- Medium-Earth Orbit (MEO) Satellites
- Low-Earth Orbit (LEO) Satellites
- Satellites vs. Fiber

Kinds of Satellites

Satellites and their properties vary by altitude:

- Geostationary (GEO), Medium-Earth Orbit



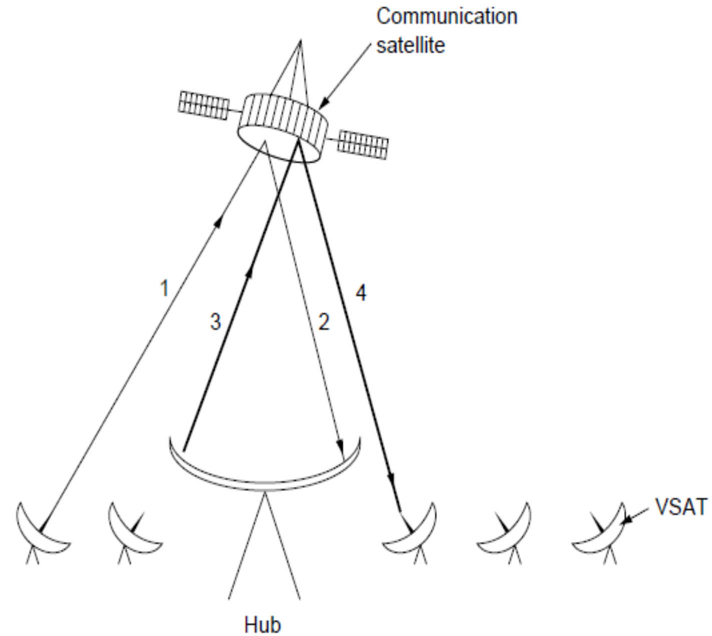
Geostationary Satellites

GEO satellites orbit 35,000 km above a fixed location

- VSAT (computers) can communicate with the help of a hub
- Different bands (L, S, C, Ku, Ka) in the GHz are in use but may be crowded or susceptible to rain.

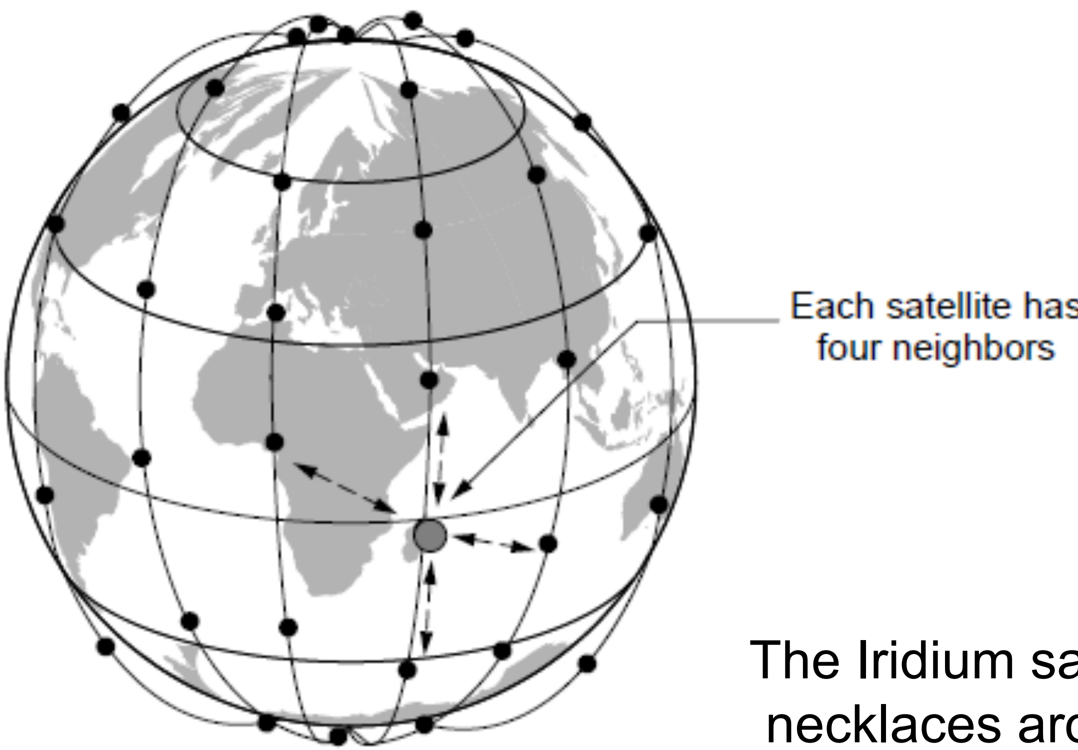
GEO satellite

VSAT
(Very Small Aperture Terminals)



Low-Earth Orbit Satellites

Systems such as Iridium use many low-latency satellites for coverage and route communications via them



The Iridium satellites form six necklaces around the earth.

Satellite vs. Fiber

Satellite:

- + Can rapidly set up anywhere/anytime communications (after satellites have been launched)
- + Can broadcast to large regions
- Limited bandwidth and interference to manage

Fiber:

- + Enormous bandwidth over long distances
- Installation can be more expensive/difficult

Link Terminology

<u>Full-duplex</u> link

- Used for transmission in both directions at once
- e.g., use different twisted pairs for each direction

<u>Half-duplex</u> link

- Both directions, but not at the same time
- e.g., senders take turns on a wireless channel

<u>Simplex</u> link

- Only one fixed direction at all times; not common

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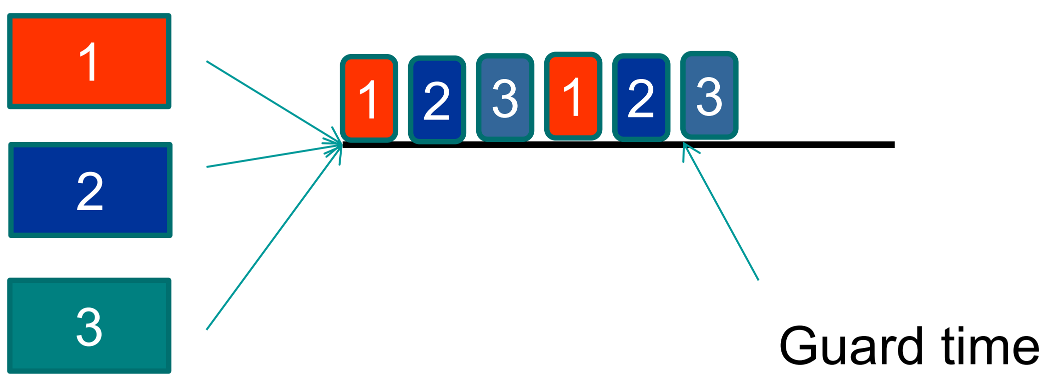
Multiplexing

- When multiple sources want to access the medium
  - Time Division Multiplexing
  - Frequency Division Multiplexing
  - Statistical Multiplexing (for curious readers)
  - Code Division Multiple Access

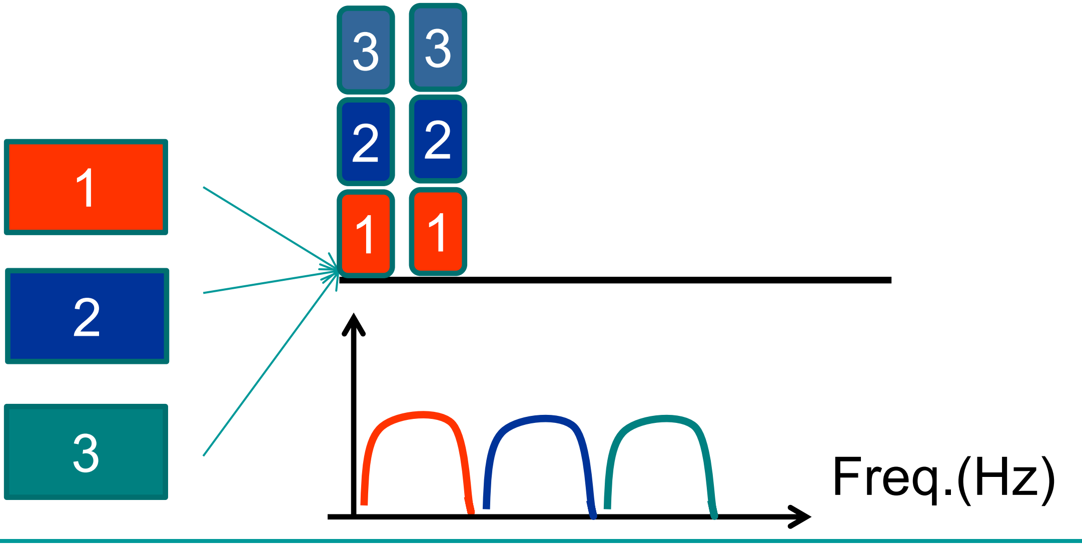
Time Division Multiplexing

- Users can send according to a fixed schedule
- Slotted access to the full speed of the media



Frequency Division Multiplexing

- Users can only use specific frequencies to send their data
- Continuous access with lower speed



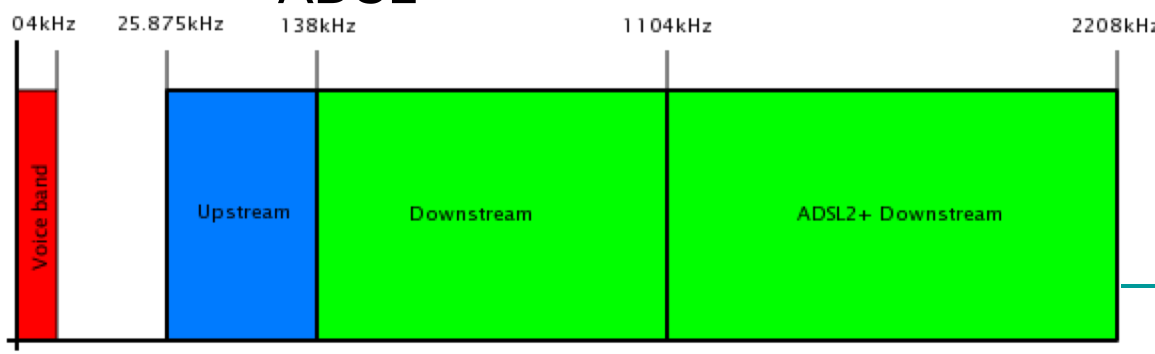
Digital Modulation

Modulation schemes send bits as signals

- Baseband Transmission
  - Signal that run from 0 up to a maximum frequency
  - E.g., Telephone system: 0 ~ 4kHz
- Passband Transmission
  - Signals that are shifted to occupy a higher range of frequencies

ADSL

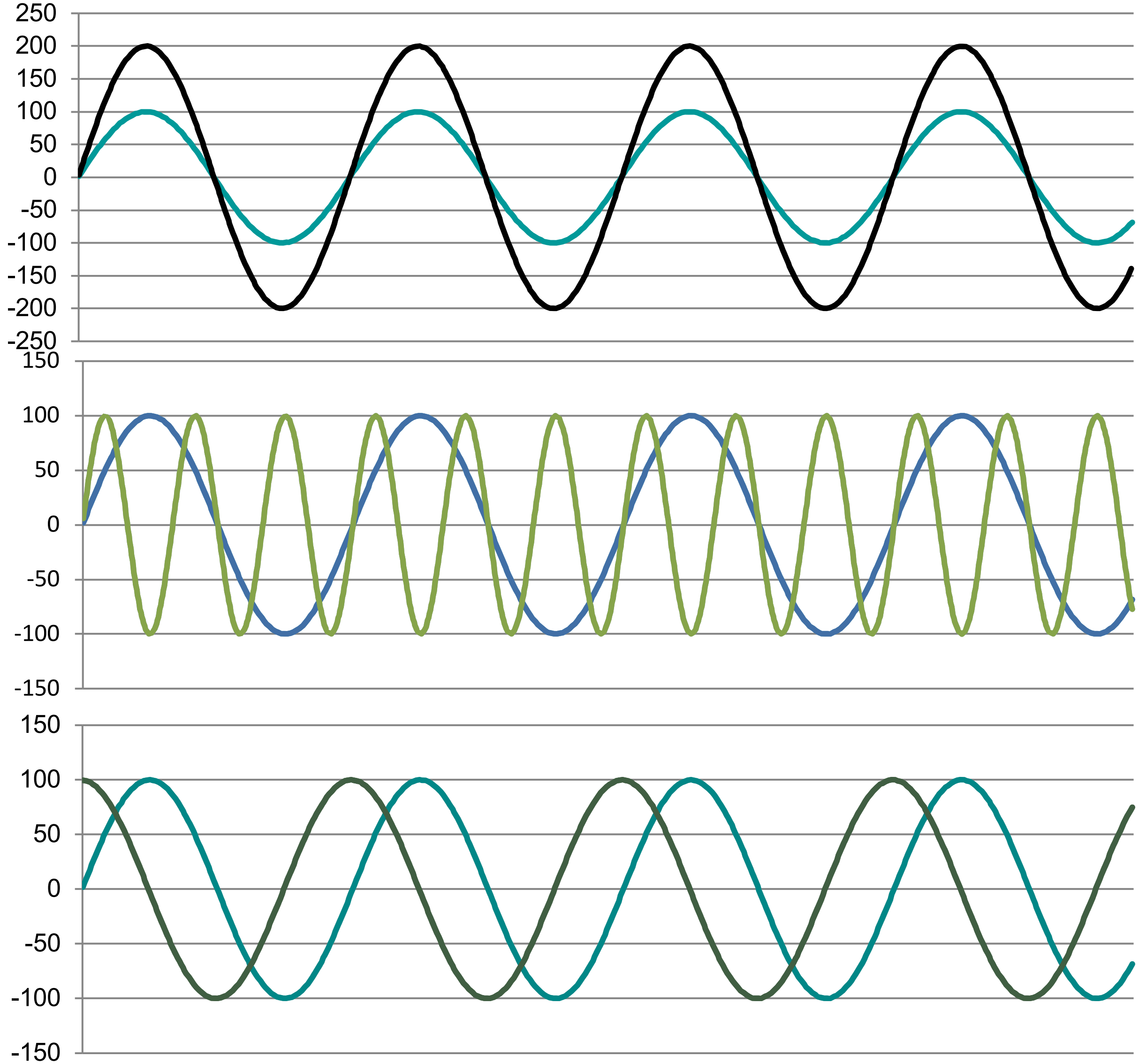
Example:



Electrical Analogue Signal to Digital

- Information on wire transmitted by variance of a physical property eg voltage, current.
  - Generating a periodic function, imagine a Sine function
- Sine function: c*sin(ax+b): Three things can change the behaviour of the function:
  - C: Amplitude, A:Frequency and B:Phase

Change in Amplitude, Frequency, & Phase



Change in Amplitude

Change in Frequency

Change in Phase

Modulation Types

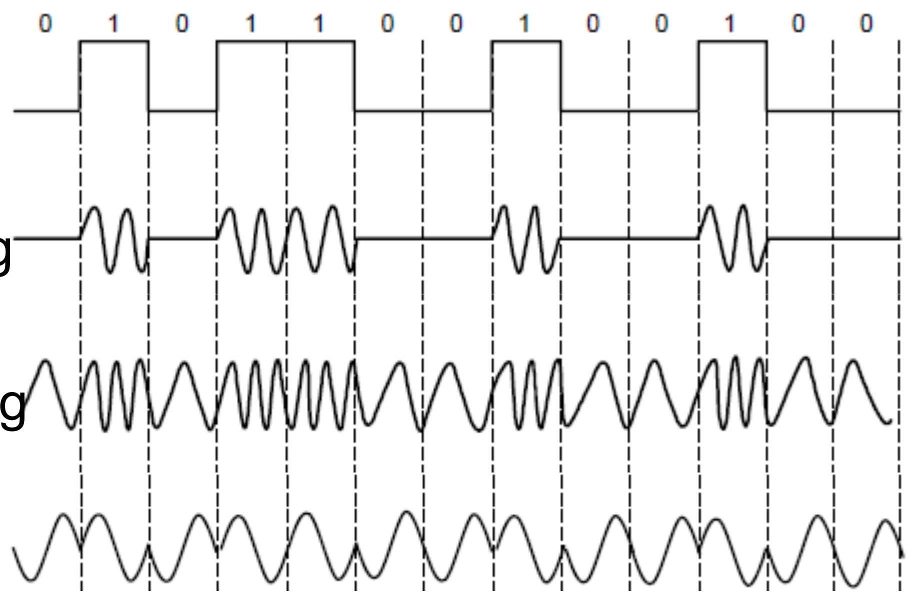
Modulating the amplitude, frequency/phase of a carrier signal sends bits in a (non-zero) frequency range

NRZ signal of bits

Amplitude shift keying

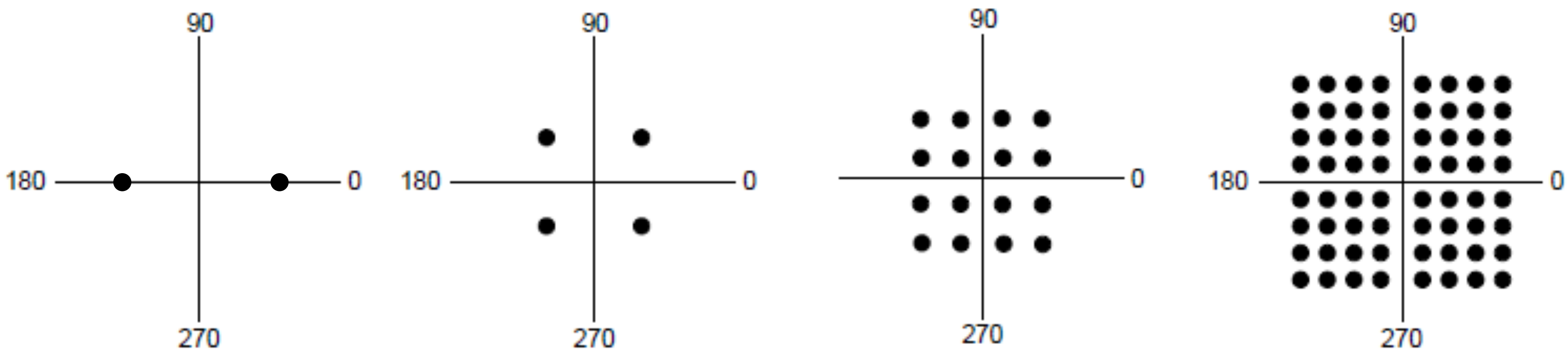
Frequency shift keying

Phase shift keying



Passband Transmission

Constellation diagrams are a shorthand to capture the amplitude and phase modulations of symbols:



BPSK
2 symbols
1 bit/symbol

QPSK
4 symbols
2 bits/symbol

QAM-16
16 symbols
4 bits/symbol

QAM-64
64 symbols
6 bits/symbol

BPSK/QPSK varies only phase

QAM varies amplitude and phase

Harry Nyquist

- Early theoretical work on determining fundamental limits for the bandwidth required for communication-heralded digital revolution

A Brief Introduction to Data Communications Theory

- How to transform continuous signals into digital values?
    - Sampling the amplitude values of the signal

- Symbol Rate (Baud Rate): number of signal changes per second

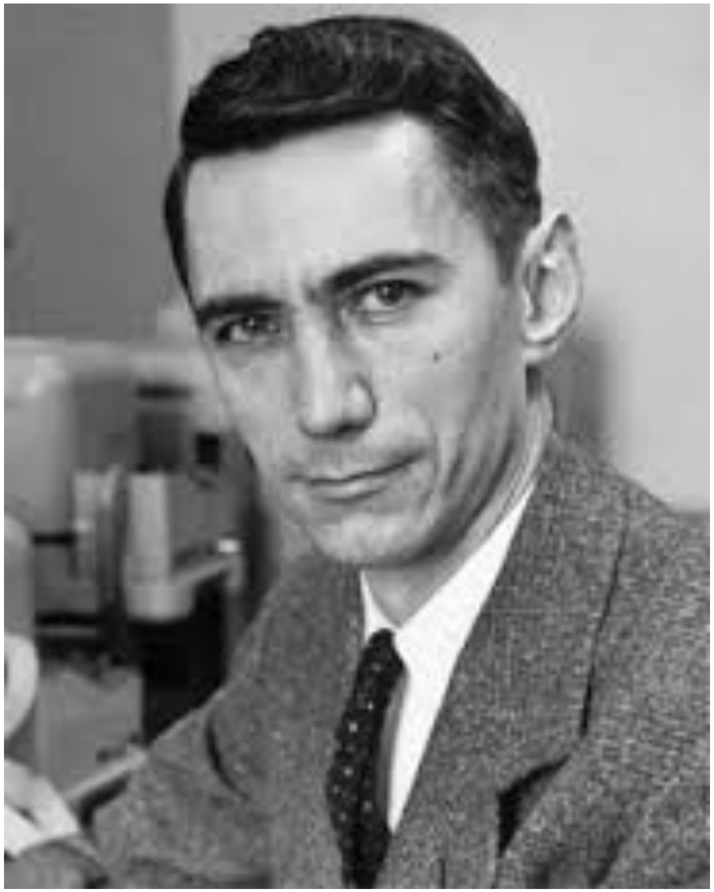
Maximum Data Rate of a Channel

- Nyquist's theorem relates the data rate to the bandwidth (B) and number of signal levels (V) (channel without noise):

$$\boxed{\text{Max. data rate} = 2B \log_2 V \text{ bits/sec}}$$

- If a signal has bandwidth B, then the signal can be fully reconstructed by sampling with 2B rate.
- If signal has V levels, each symbol can be represented by $\log_2 V$ bits.

Claude Shannon



- Father of Information theory.
- 1948 monograph –"The mathematical theory of communication" defined a new area;
- 1949 monograph- "Communication Theory of Secrecy Systems" is another foundational work on modern Cryptography

Maximum Data Rate of a Channel

- Shannon's theorem relates the data rate to the bandwidth (B) and signal strength (S) relative to the noise (N):

$$\boxed{\text{Max. data rate} = B \log_2(1 + S/N) \text{ bits/sec}}$$

How fast signal can change

How many levels can be seen

Example 1

Q: Given the signal-to-noise ratio (SNR) of 20 dB, and the bandwidth of 4kHz (telephone communications), what is the maximum data rate according to Shannon's theorem?

Ans:

C = 4000 log2(1 + 100) = 4000 log2 (101) = 26.63 kbit/s. Note that the value of S/N = 100 is equivalent to the SNR of 20 dB

Example 2

Q: If a binary signal is sent over a 3-kHz channel whose signal-to-noise ratio is 20 dB, what is the maximum achievable data rate?

Ans:

SNR of 20 dB = S/N = 100.

Since $\log_2(101)$ is about 6.658, the Shannon limit is about 19.975 kbps but the Nyquist limit is 6 kbps.

The bottleneck is therefore the Nyquist limit, giving a maximum channel capacity of 6 kbps

Summary

- Bandwidth & delay
- Message Latency = Propagation + Transmission delay
- Wired and Wireless Mediums, complications of wireless and attenuations of the signal
  - For different applications, what type of network is more suitable?
- Full-duplex vs Half-duplex vs Simplex
- Bit representation in the physical layer
- Multiplexing - multiple access to shared medium
- Nyquist's Theorem
- Shannon's Theorem