Week 2 – Physical Layer

COMP90007 Internet Technologies

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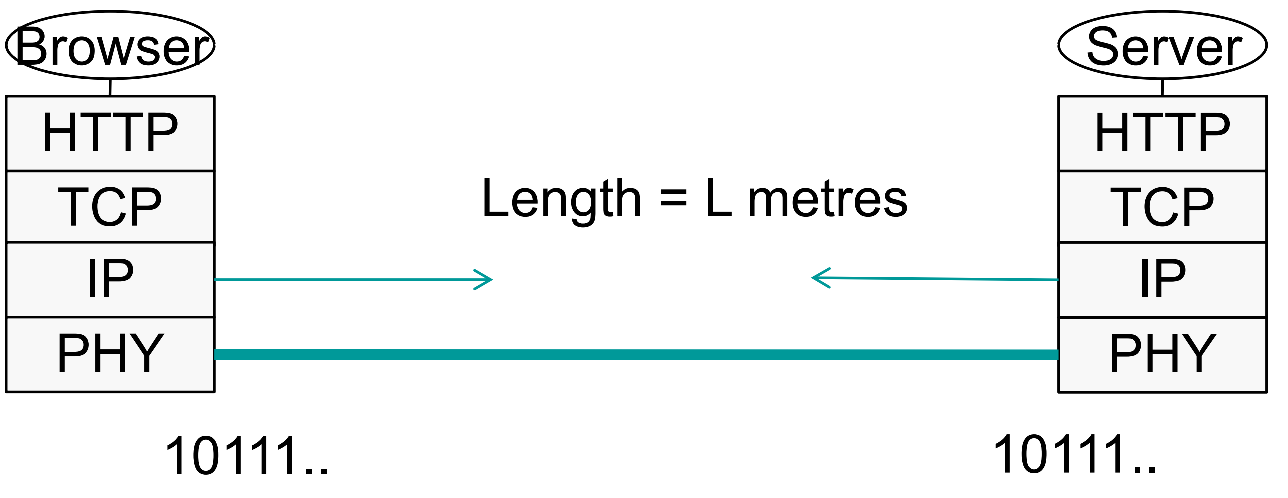
What is the Physical Layer ?

- 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 electrical, timing and mechanical interfaces of the network
  - Electrical: voltage levels, signal strength …
  - Timing: data rate …
  - Mechanical: material, cable length …

Link Model

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



Link Model

- ***Bandwidth*** is usually treated as rate of transmission in bits/second.

- ***Delay*** 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 a Fibre Optic Cable?

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.

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.

The Bandwidth Revolution?

- CPU speeds increase by a factor of ~20 per decade
  - 1981: PC 4.77MHz vs 2001: PC 2 GHz
- Current CPU speed now approaching physical limits - constrained by physical properties pertaining to granularity of engraving on silicon
- Evolutionary steps in available bandwidth:

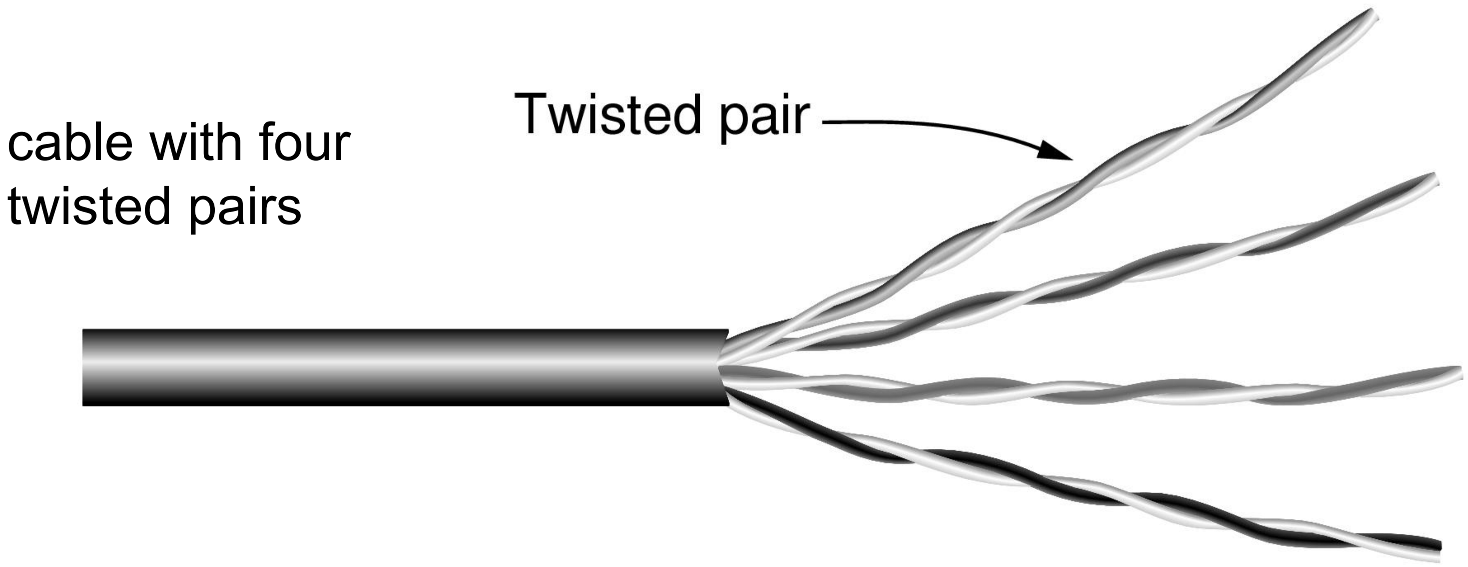
  Bandwidth increases by a factor of ~125 per decade (1981: Modem 56kbps vs 2001: Net 1Gbps)
- Current bandwidth available up to 65 Tbps - vastly exceeding the rate at which we can convert electrical impulses to optical pulses

Transmission Media

- How many different types of physical media can you think of?
- Various physical media can be used to transmit data, but all of them are affected by physical properties
- How far and how much data a medium can carry has a lot to do with signal attenuation.
- Attenuation: 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 interference: canceling out electromagnetic interference from external sources
- Distance up to <5km, repeaters can extend this distance



Properties and Types of Twisted Pair

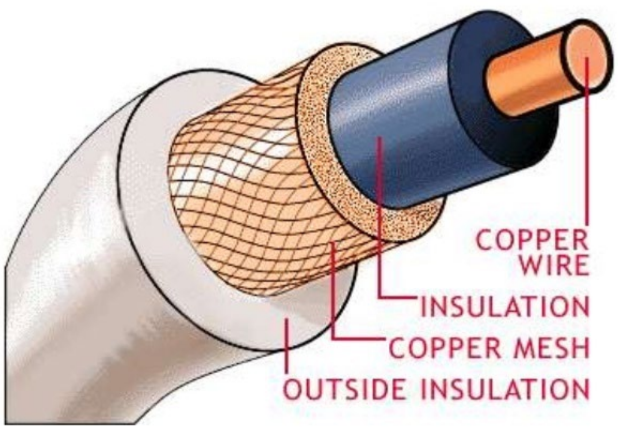
- Bandwidth depends on distance, wire quality/ density
- Cat 3 - 2 wires, 4 pairs in sheath, 16MHz
- Cat 5 - 2 wires, 4 pair in sheath, more twists = less interference, higher quality over longer distance, 100 MHz
- Cat 8 – 2000 MHz

Don’t worry about this unit for now, just higher value is better!

Coaxial Cable (Co-ax)

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

A diagram of a coaxial cable

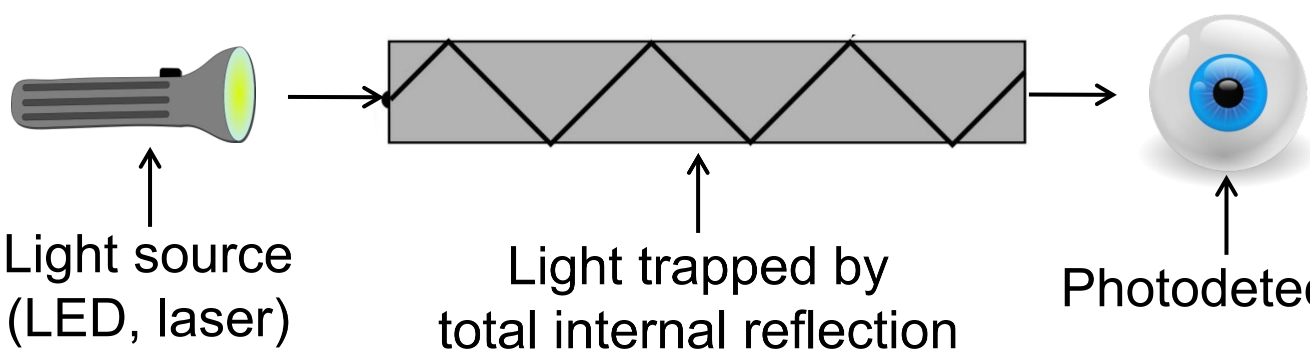


Fibre Optics

- Fibre has enormous bandwidth (THz) and tiny signal loss
- Data transmission over a fibre of glass
- Common for high rates and long distances
  - e.g. backbone links between ISP facilities, Fibre-to-the-Home (FTTH)

Transmission of Light Through Fibre

- 3 components: light source, transmission medium, detector
- Semantics: light = 1, no light = 0 (basic binary system)
- Signalling using LED’s or semiconductor lasers
- A detector generates electrical pulse when light hits it
- Refraction between air/silica boundary is compensated for by design - total internal reflection



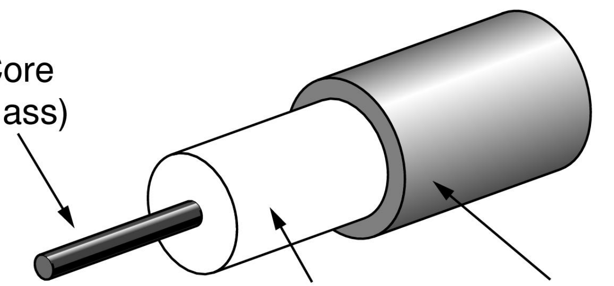
Fibre Optic Cables

Single-mode

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

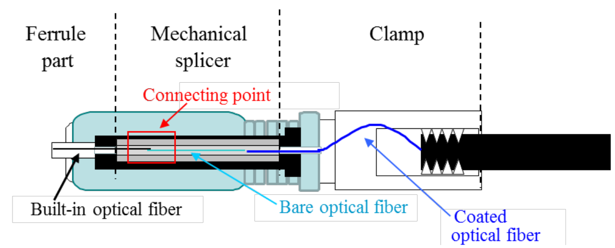
Multi-mode

- 50um core, light can bounce
- Used with LEDs for cheaper, shorter distance links



Fibre Optic Connections

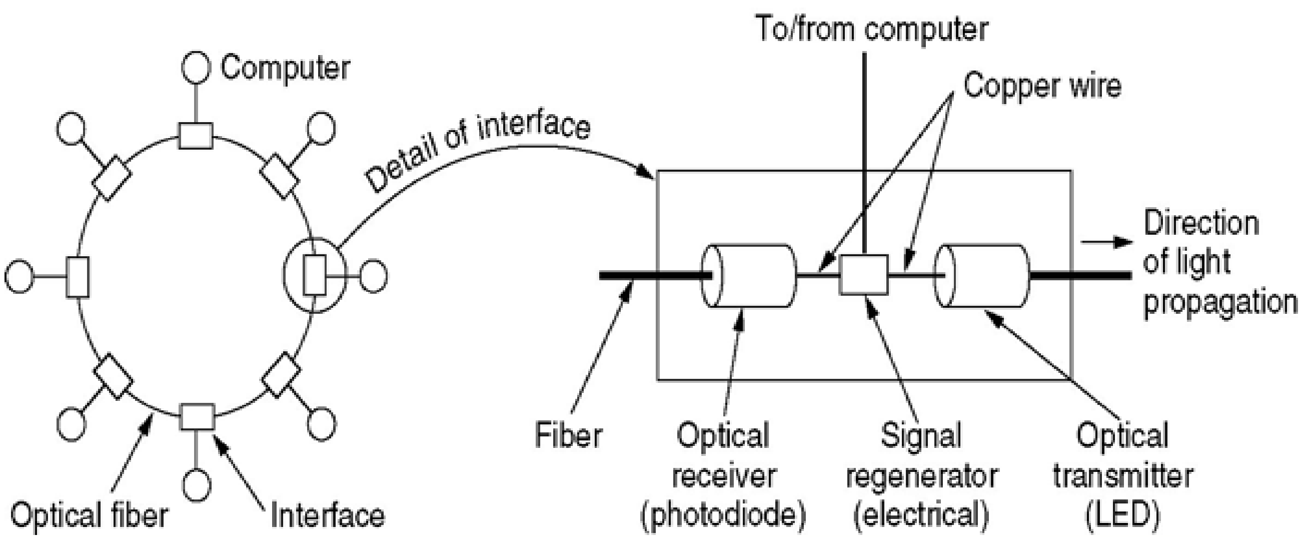
- Connectors and Fibre Sockets (10-20% loss)
- Mechanical Splice (10% loss)
- Fusion (<1% loss)



Examples: mechanical splice

Fibre Optic Networks

- Fibre optic cable is a scalable network media - LAN, WAN, long distances
- Fibre optic cable networks can be organised either as a ring or as a bus network (series of point to point connections)



Fibre Optic Ring

Comparison: Wires and Fibre

Comparison of the properties of wires and fibre:

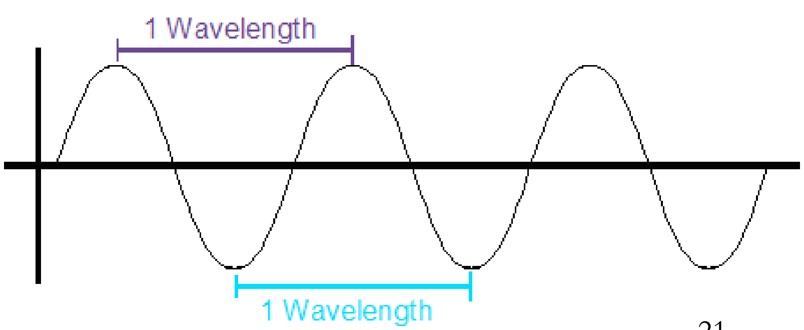
Property	Wires	Fibre
Distance	Short (100s of m)	Long (tens of km)
Bandwidth	Moderate	Very High
Security	Easy to tap	Hard to tap
Cost	Inexpensive	More Expensive
Convenience	Easy to use	Harder to use

Wireless Transmission

- Mobile users requires a **mobility** enabled network - contrast with the wired networks
- Wireless networks can provide advantages even in fixed location environments
- Wireless data transmission networks have a common basis - **electromegnatic wave propagation**
    - Unlike previous media, wireless signals are **broadcasted** over a region
    - Potential **signal collisions** – Need regulations

Basics of Electromagnetic Waves

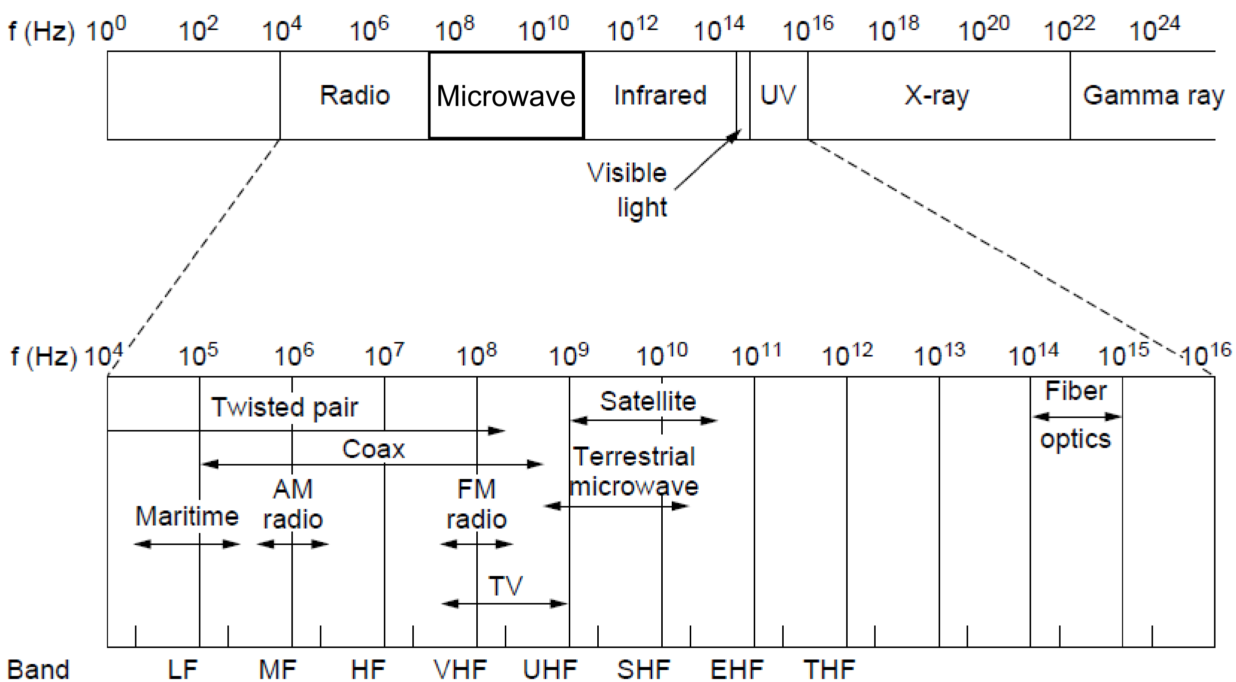
- **Frequency:** Number of oscillations per second of a wave, measured in Hertz (Hz).
- **Wavelength:** Distance between two consecutive minima or maxima.
- **Speed:** All EM waves travel at the same speed - the speed of light ~ $3*10^8$ m/s
- Fundamental relationship:
  - Wavelength x Frequency = Speed of Light
  - Units: (m) x (1/s) = (m/s)



Electromagnetic Spectrum

Different bands have different uses:

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



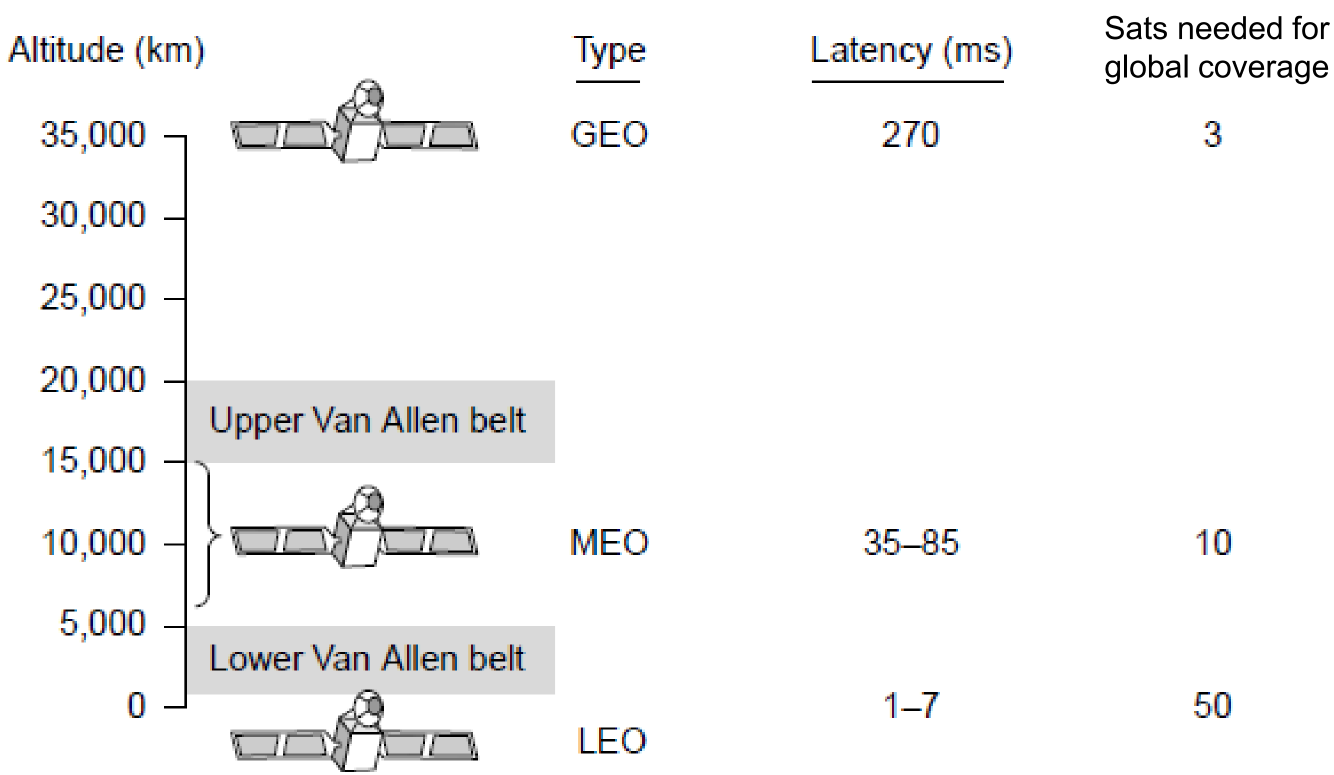
Communication Satellites

Satellites are effective for broadcast distribution and anywhere/anytime communications

- Types of satellites:
  - Geostationary (GEO) Satellites
  - Medium-Earth Orbit (MEO) Satellites
  - Low-Earth Orbit (LEO) Satellites

Types of Satellites

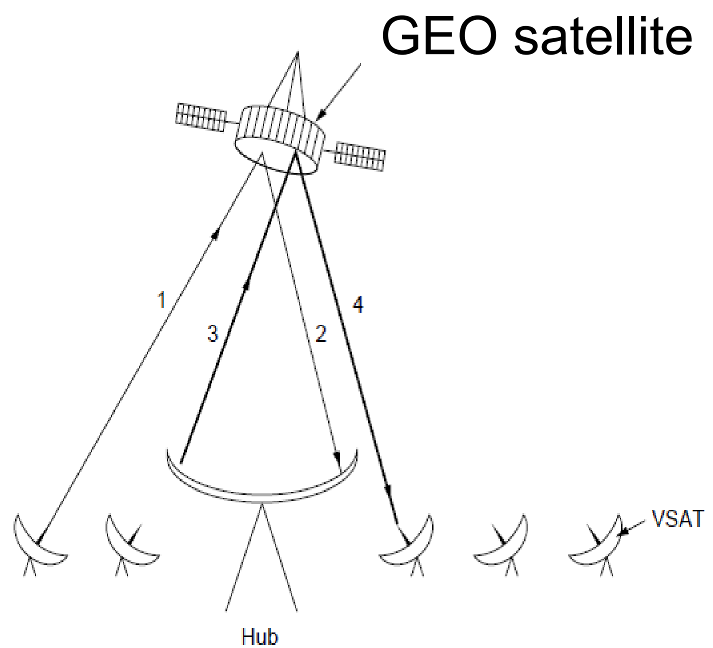
Satellites and their properties vary by altitude



Geostationary Satellites

GEO satellites orbit 35,000 km above a fixed location

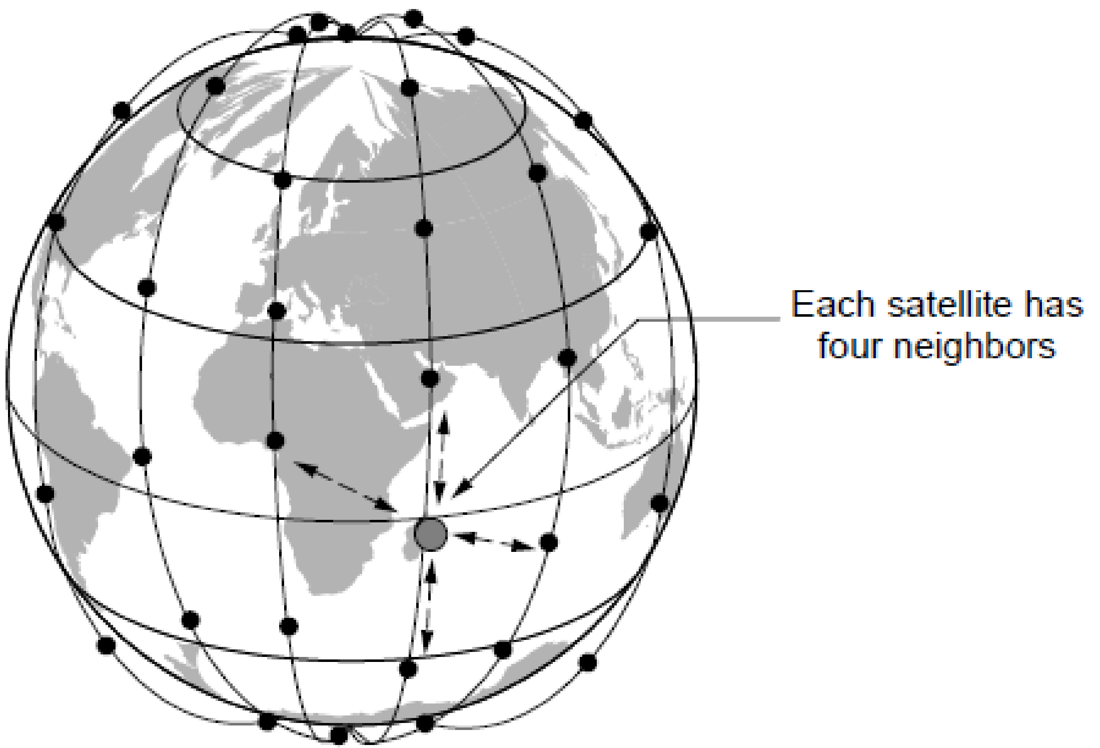
- VSAT (computers) can communicate with the help of a hub
- Different bands (L, S, C, Ku, Ka) in the GHz are in use but may be crowded or susceptible to rain.



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



Satellite vs. Fibre

Satellite:

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

Fibre:

+ Enormous bandwidth over long distances
- Installation can be difficult in rural areas

Wireless vs. Wires/Fibre

Wireless:

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

Wires/Fibre:

- \+ 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

Data Communication using Signals (1)

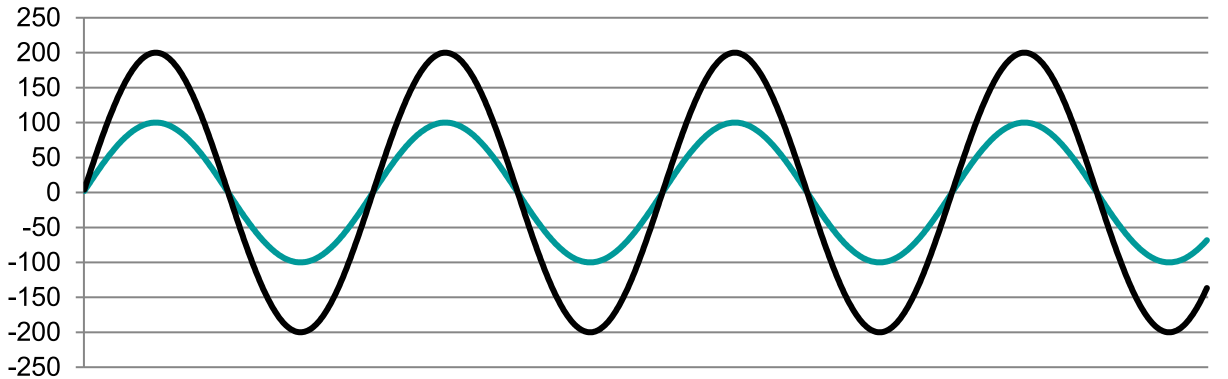
- Information is transmitted by varying a physical property e.g. voltage, current

- For a sinewave :

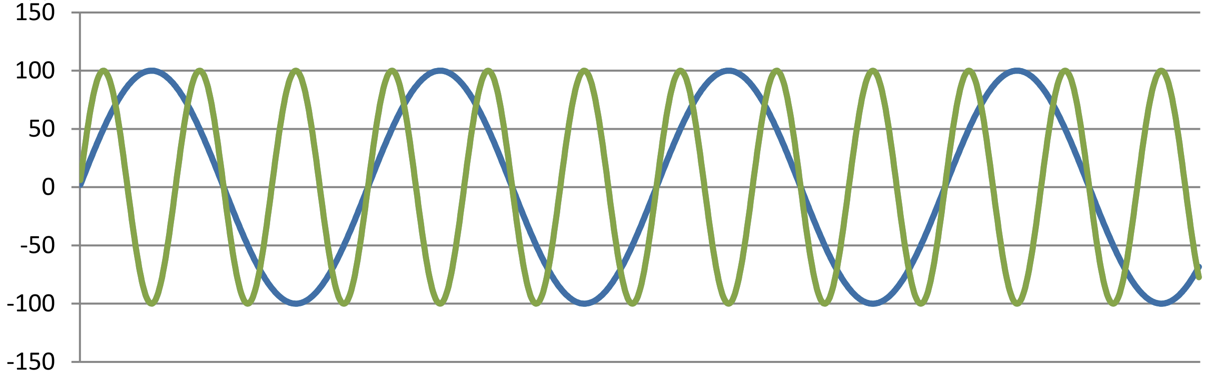
  function: $c * \sin(a * t + b)$

  c: amplitude, a/(2π):frequency and b:phase can change the behaviour of the function.

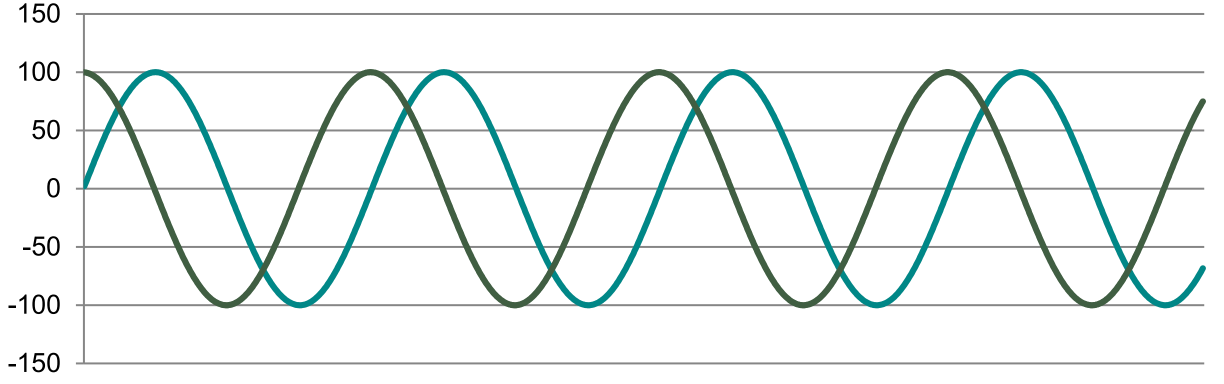
Data Communication using Signals (2)



Change in Amplitude



Change in Frequency



Change in Phase

Digital Modulation

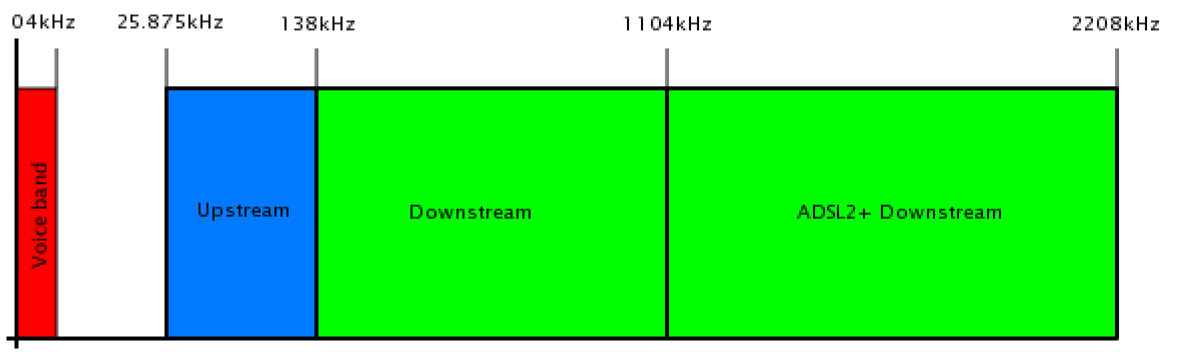
Modulation schemes send bits as signals

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



Example: ADSL

Modulation Types

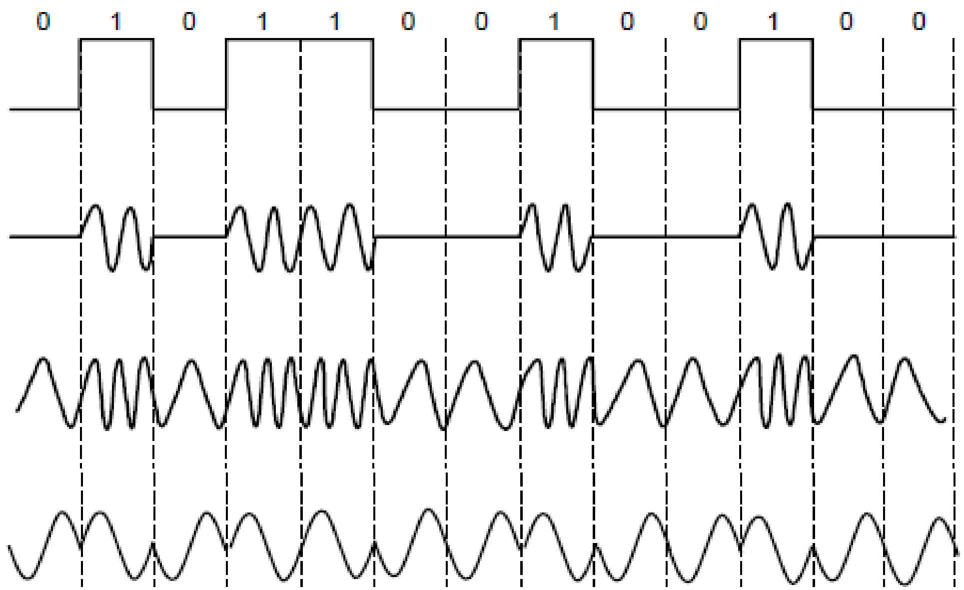
- Modulating the amplitude, frequency/phase of a carrier signal sends bits in a (non-zero) frequency range

NRZ signal of bits

Amplitude shift keying

Frequency shift keying

Phase shift keying



Data Communication using Signals (3)

- How would the receiver handle the signal to understand its meaning?
- How many different types of signals are there in each example?

Symbol Rate

- One symbol (signal element) can represent multiple bits (data elements)
- Symbol Rate (Baud Rate): number of signal changes per second

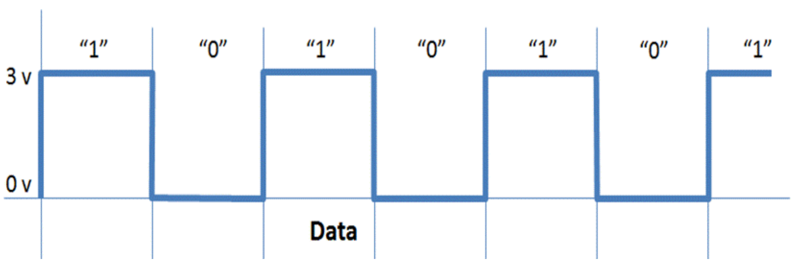


Figure 1. Data bits where logical "0" and "1" are represented by 0 volts and 3 volts respectively

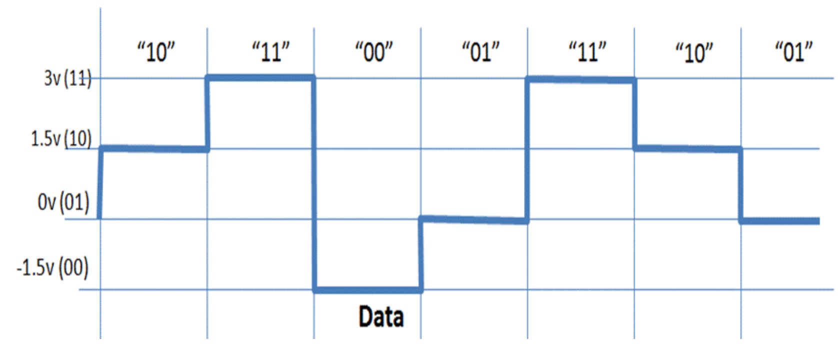


Figure 2. Four signaling levels per clock cycle can represent two data bits.

Source of figures: http://mason.gmu.edu/~rmorika2/Baud_Versus_Bits_per_second.htm

How much can we put on a link?

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

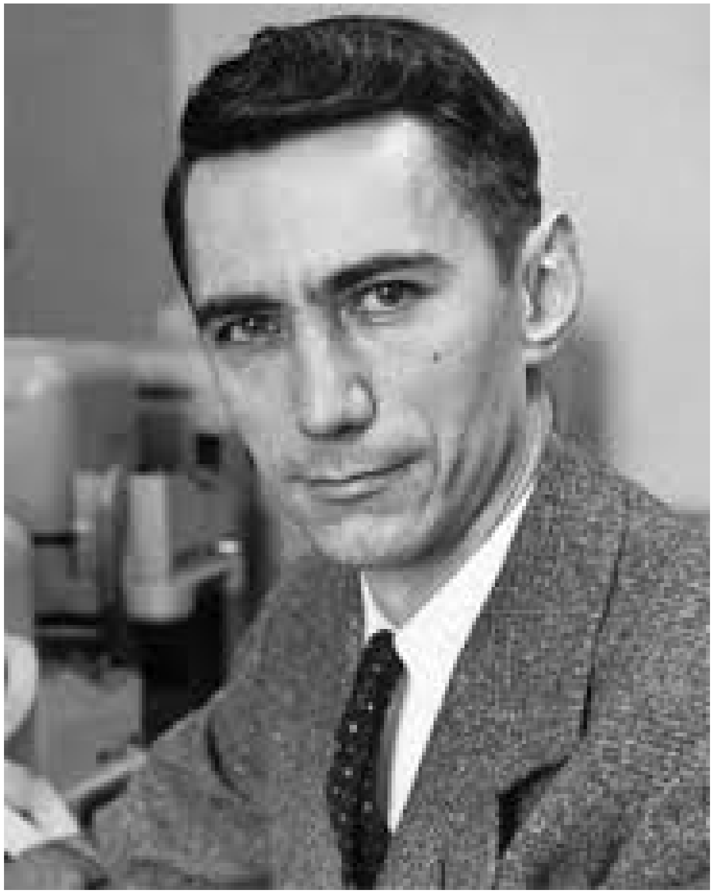
Maximum Data Rate of a Channel

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

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

- Increase the bandwidth B can increase the data rate.
- If signal has V levels, each symbol can represent $\log_2 V$ bits.

What if there is noise?



- Claude Shannon - Father of Information theory.
- Contributed to information theory and 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):

$$\boxed{\text{Max. data rate} = \underbrace{B}_{\substack{\text{How fast signal}\\ \text{can change}}} \log_2(1 + \underbrace{S/N}_{\substack{\text{How many levels}\\ \text{can be seen}}}) \text{ bits/sec}}$$

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?

Example 2

<u>**Q**</u>: 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?

Link Terminology

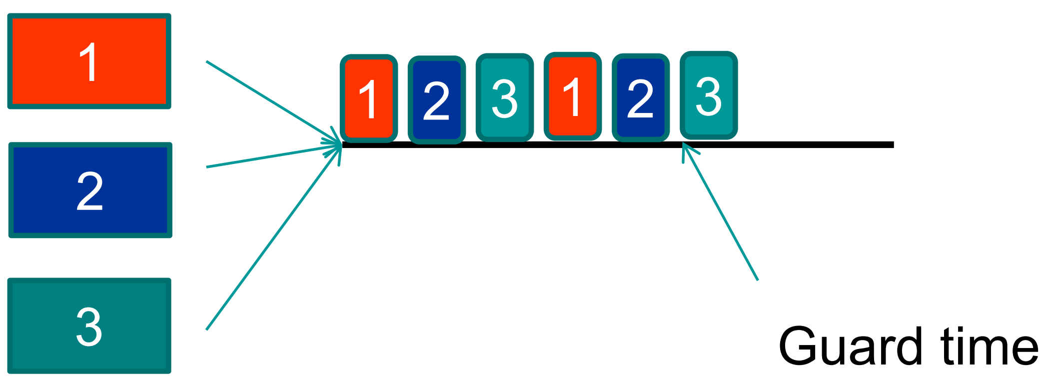
- Full-duplex link
  - Used for transmission in both directions at once
  - e.g., use different twisted pairs for each direction
- Half-duplex link
  - Both directions, but not at the same time
  - e.g., senders take turns on a wireless channel
- Simplex link
  - Only one fixed direction at all times; not common

Multiplexing

- When multiple sources want to access the medium
  - Time Division Multiplexing
  - Frequency Division Multiplexing
  - Statistical Multiplexing
  - 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