Week 2 – Physical Layer

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COMP9000 / Internet Technologies

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What is the Physical Layer ?

- Recall the layer hierarchy from network reference models
  - In OSI model, the physical layer is the lowest layer
  - In TCP/IP model, the physical layer's properties 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 …

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Outline

- Timing aspect
  - Bandwidth and Latency
- Mechanical aspect: transmission media
  - Twisted pair
  - Co-axial
  - Fibre optics
  - Wireless: EM waves, satellites
- Electrical aspect
  - Data communication using signals
  - Digital modulation
- Capacity of a channel
  - Maximum data rate
  - Multiplexing

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Link Model

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

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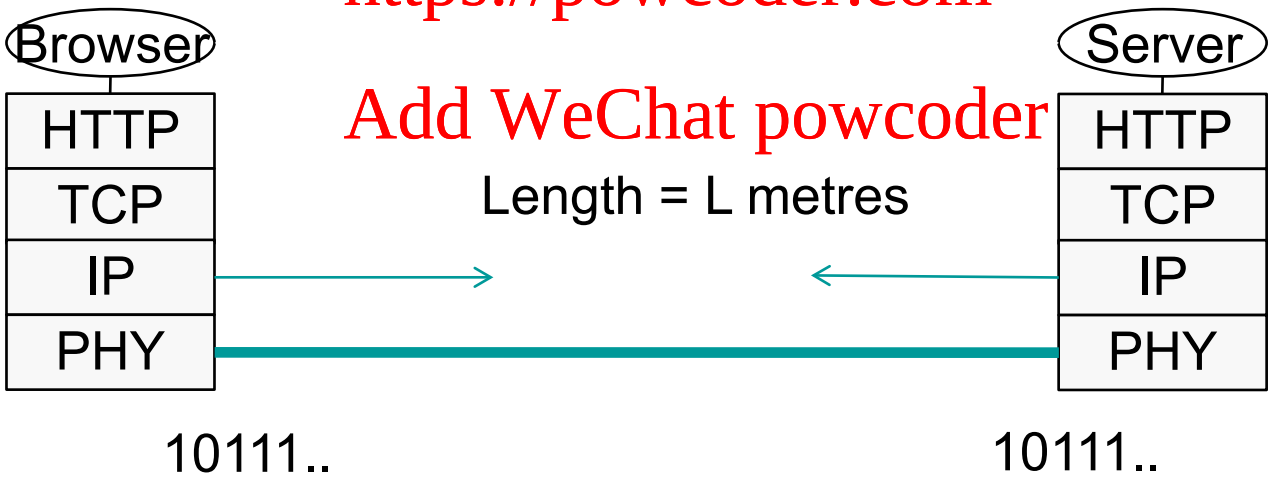

Link Model

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

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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?

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

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

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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 (bps) = 100 m sec
- P-delay = 5 (km)/200000 (km/s) = 0.025 m sec
- Latency = 100.025 m sec

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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

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The Growth of Bandwidth

- CPU speeds increase by a factor of ~20 per decade
  - 1981: PC 4.77MHz vs. 2020: PC 4GHz
  - Current CPU speed now approaching physical limits - constrained by physical properties pertaining to granularity of engraving on silicon
- Bandwidth increases by a factor of ~125 per decade
  - 1981: Modem 56kbps
  - Current bandwidth available up to 65 Tbps - vastly exceeding the rate at which we can convert electrical impulses to optical pulses

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- Electrical aspect
- Capacity of a channel
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  - Multiplexing

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Transmission Media

- How many different types of physical media can you think of?
  - Wired: twisted pair, coaxial, fibre optics
  - Wireless: electromagnetic waves and satellites
- Various physical media can be used to transmit data, but the performance is affected by physical properties.

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Signal Attenuation

- The loss or reduction in the amplitude (strength) of a signal as it passes through a medium.
- Signal attenuation impacts how far and how much data a medium can carry.

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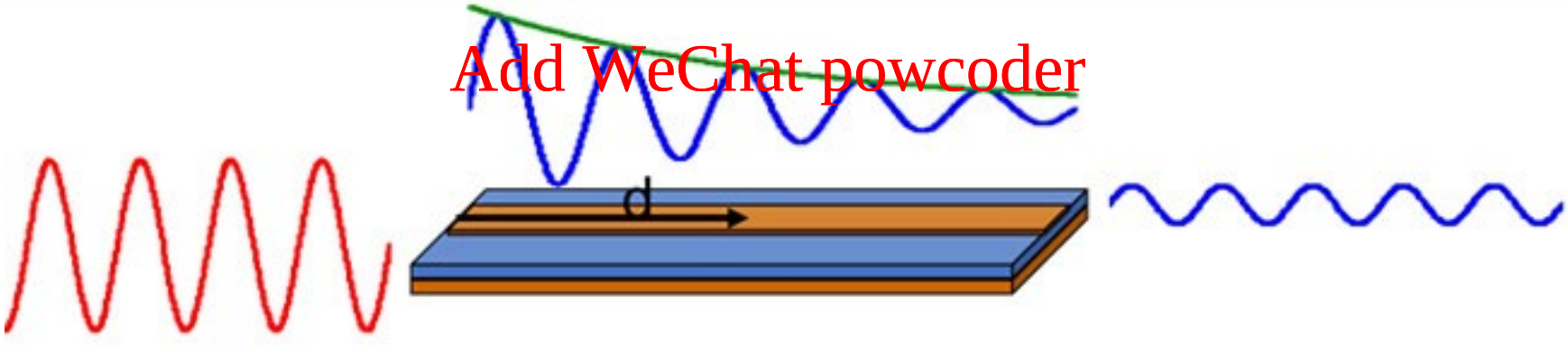

Image source: https://www.signalintegrityjournal.com/articles/1734-how-to-reduce-attenuation-in-a-differential-channel

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

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cable with four twisted pairs

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

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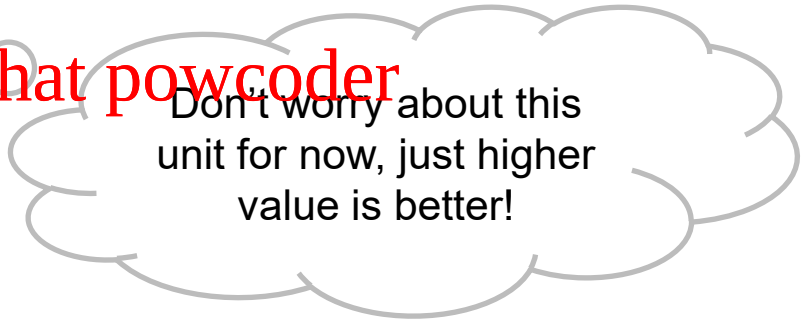

Coaxial Cable (Co-ax)

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

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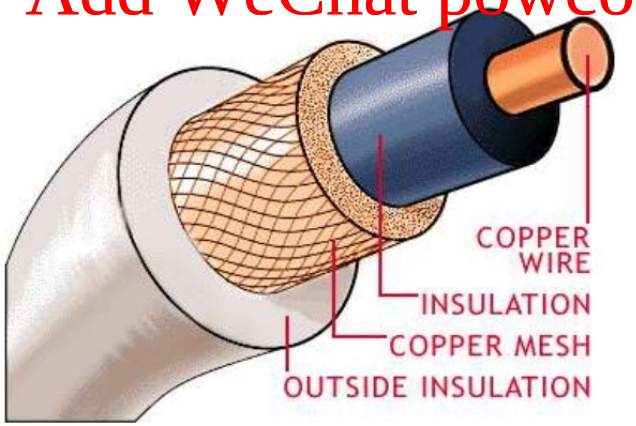
A diagram of a coaxial cable



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)

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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

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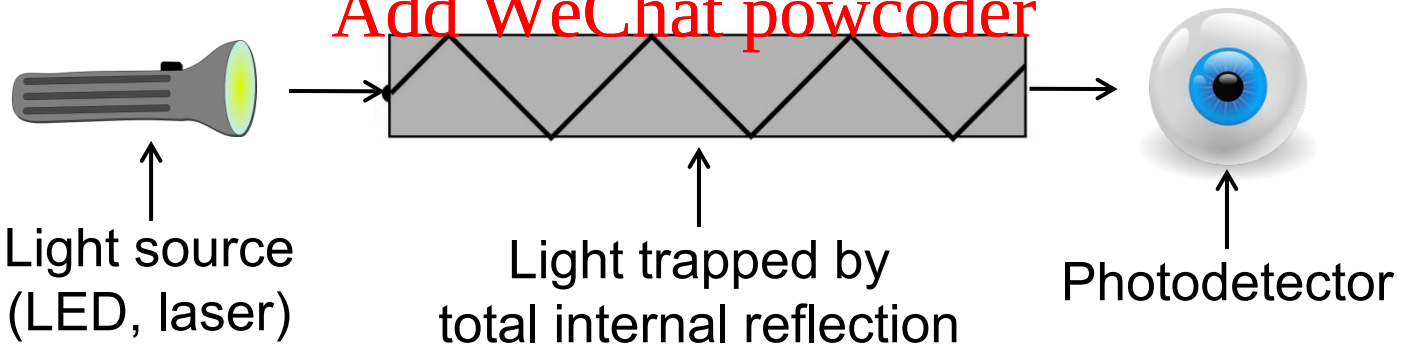

Fibre Optic Cables

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

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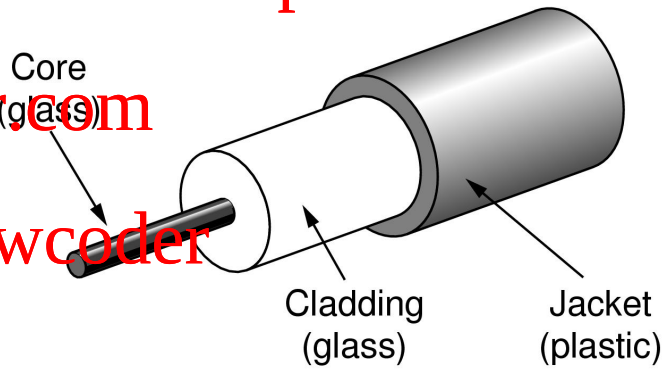

Fibre Optic Connections

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

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Example: 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)

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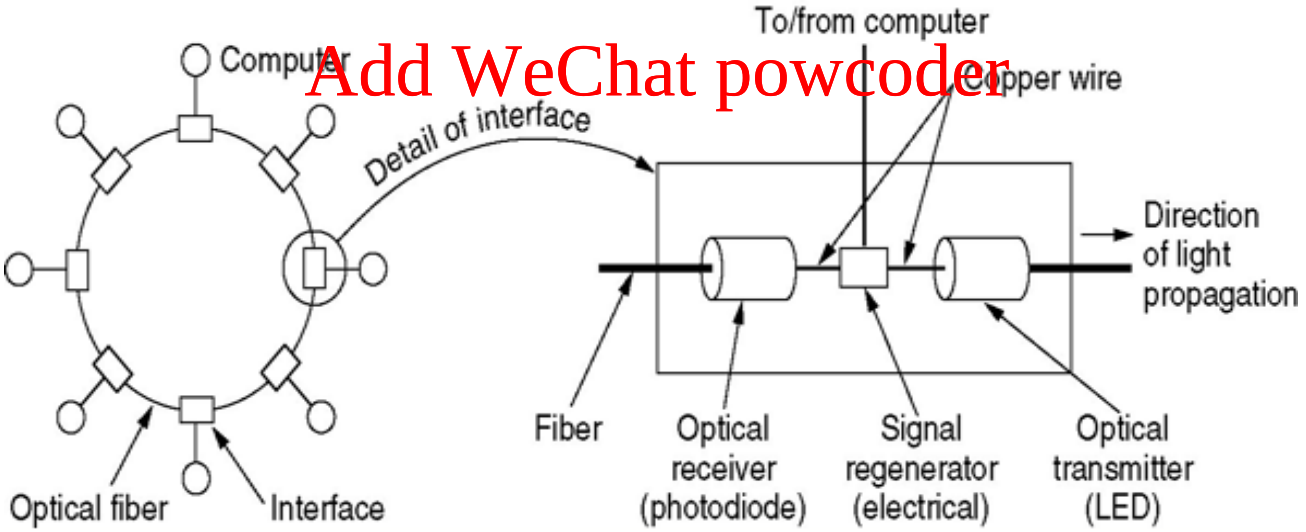

Fibre Optic Ring

Comparison: Wires and Fibre

Comparison of the properties of wires (i.e. twisted pairs and co-ax cable) 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

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