TU/e

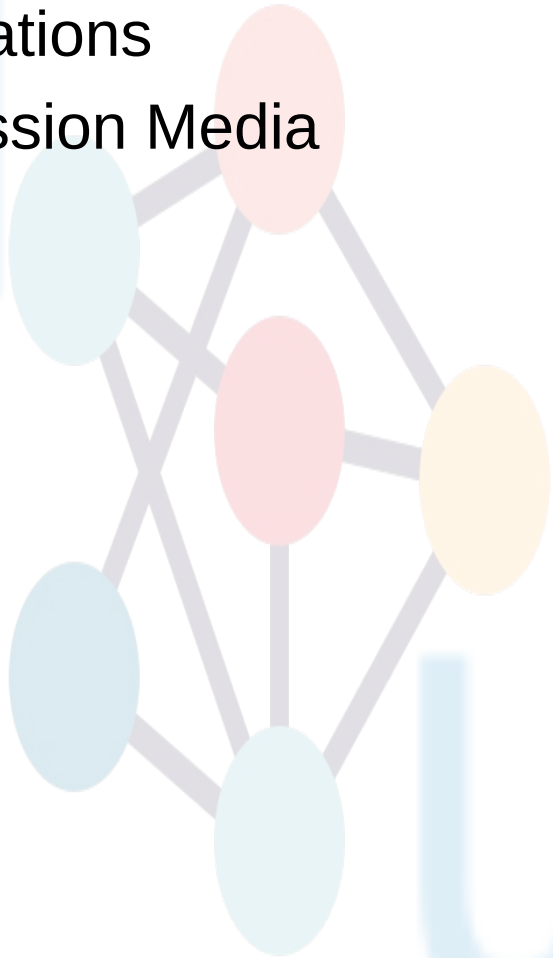
CI0121 Computer Networks

Physical Layer

Profesores ECCI

Physical layer - agenda

- Data Communications
- Guided Transmission Media



Physical layer

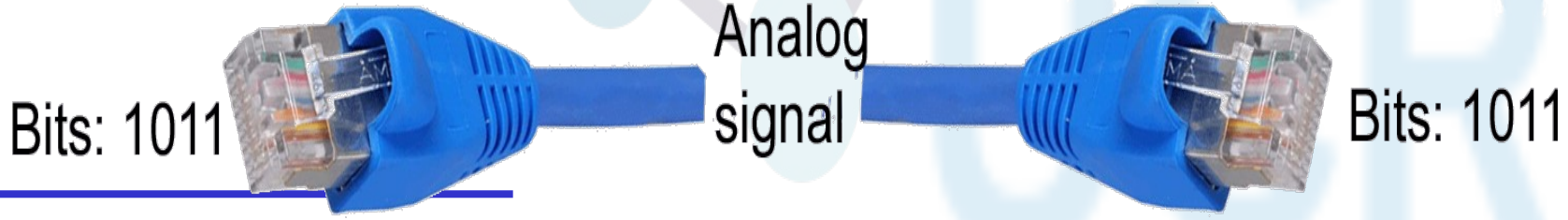
Foundation on which other layers build

- Properties of wires, fiber, wireless limit what the network can do

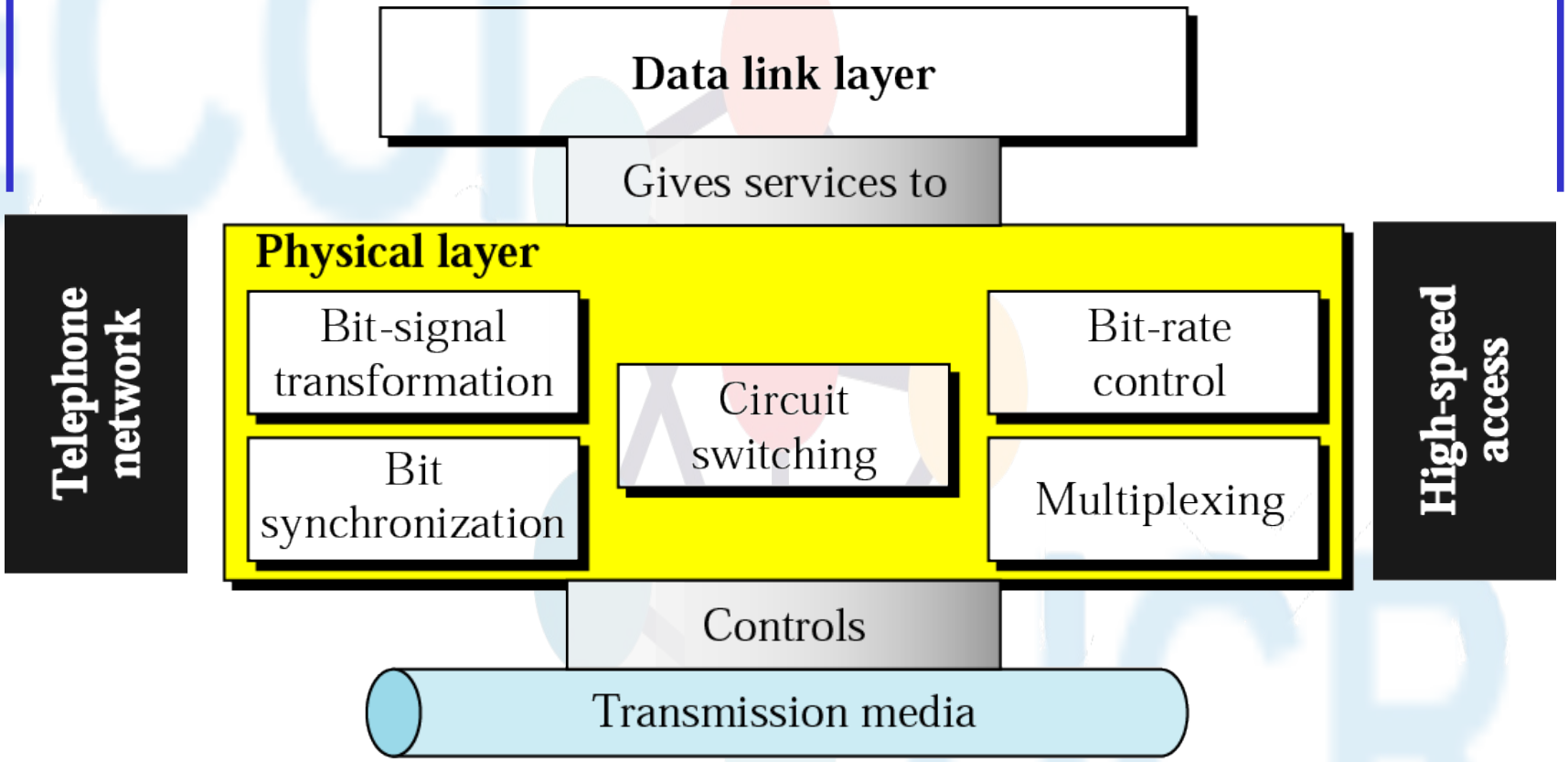
Application
Transport
Network
Link
Physical

Key problem is to send (digital) bits using only (analog) signals

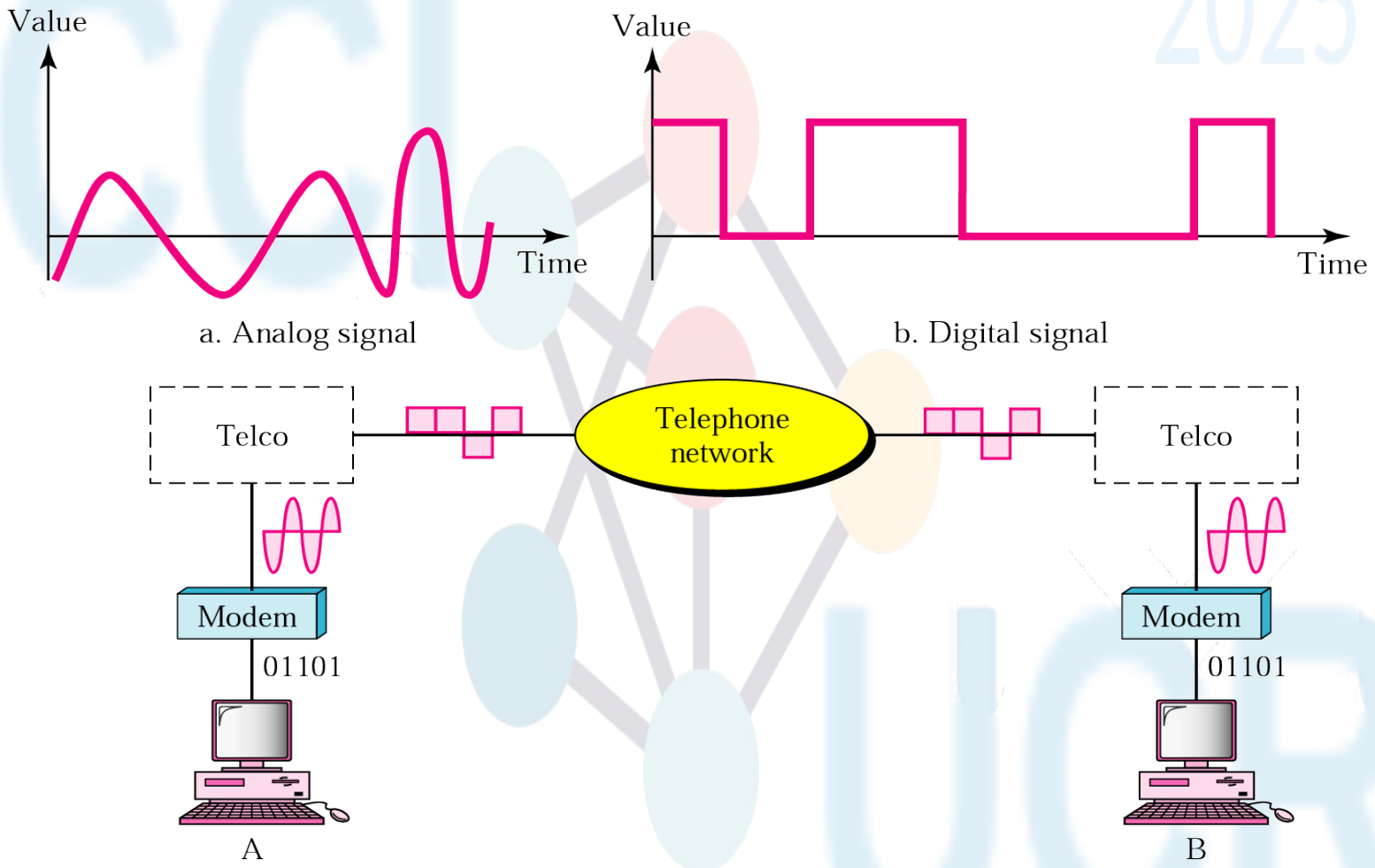
- This is called modulation



Physical Layer



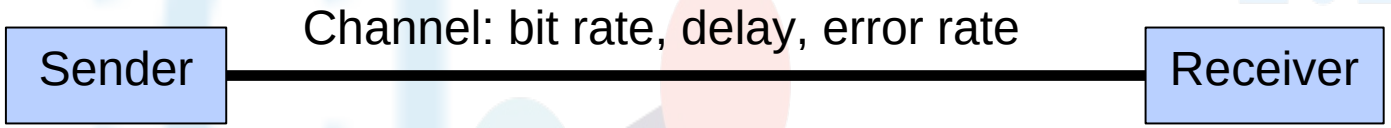
Analog vrs Digital



Physical Layer Issues

- Media: wires, fiber, satellites, radio
- Signal propagation: bandwidth, attenuation, noise
- Modulation: how bits are represented as voltage signals
- Fundamental limits: Nyquist, Shannon

Abstract Model of a Link



- Bit rate: bits/sec depends on the channel's bandwidth
- Delay: how long does it take a bit to get to the end?
- Error rate: what is the probability of a bit flipping?

Link Terminology

Simplex link

- Only one fixed direction at all times; not common

Half-duplex link

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

Full-duplex link

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

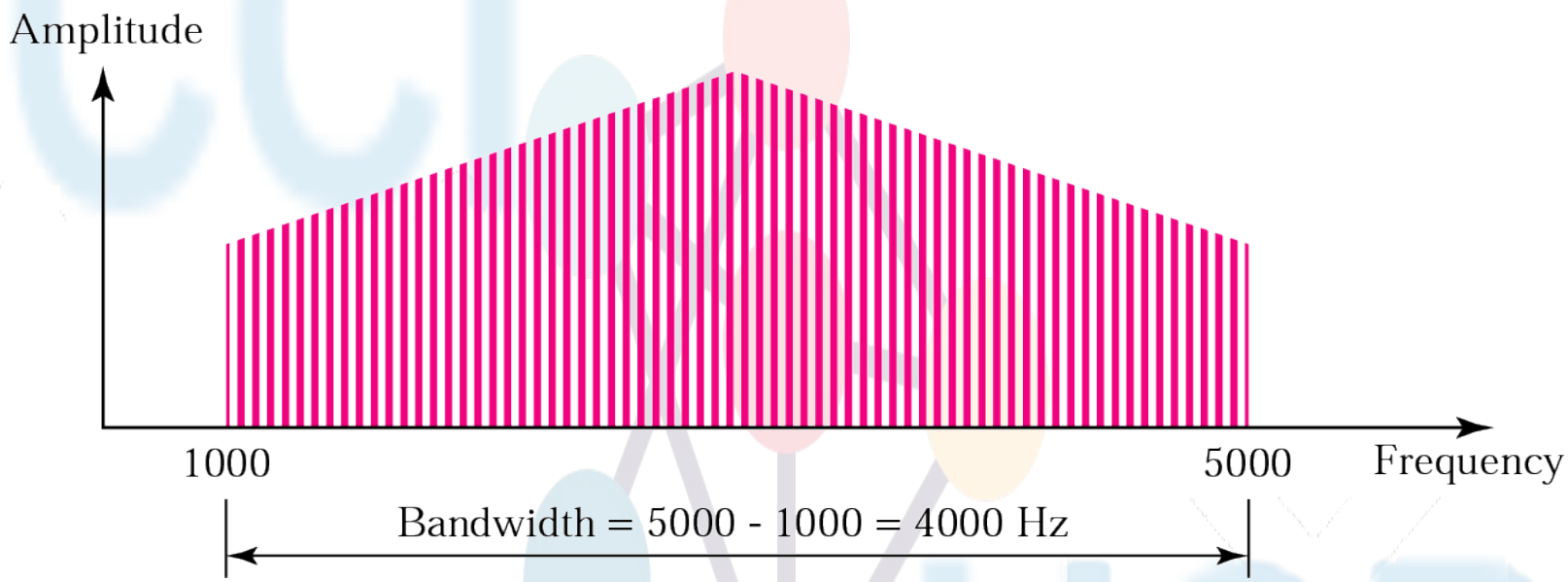
Bandwidth-Delay Product

- Bits have a physical size on the channel!
- Storage capacity of a channel is: bit rate x delay
- Example:
  - 100 Mbps 5000-km fiber, delay = 50 msec
  - In 50 msec we can pump out 5 million bits
  - So the fiber can store 5 million bits in 5000 km
  - 1 km holds 1000 bits so a bit is 1 meter long
  - At 200 Mbps, a bit is 0.5 m long

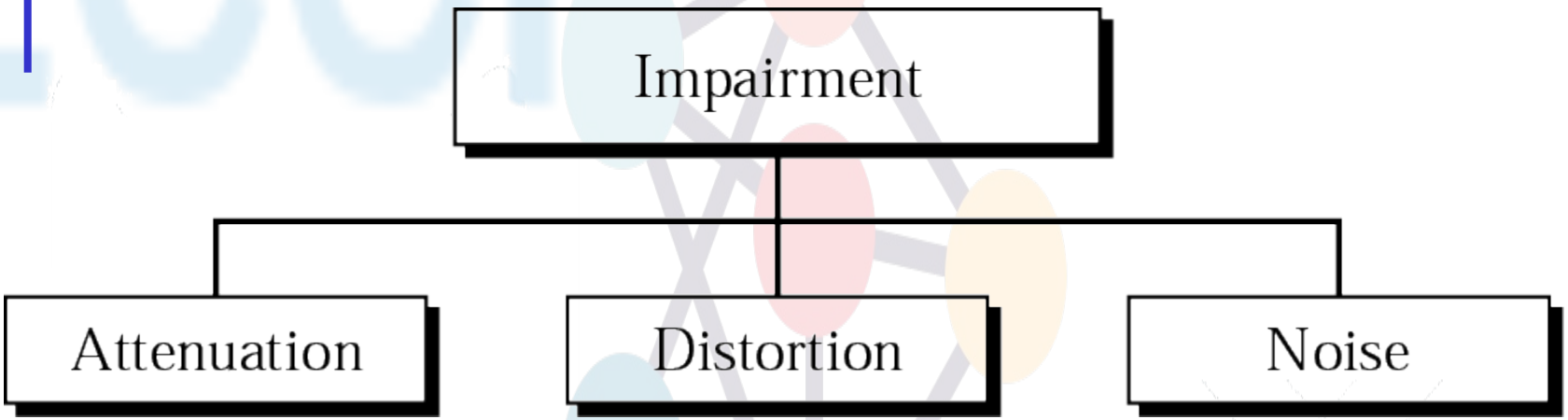
Signal propagation over a wire

- The signal has a finite propagation speed (2/3 c)
- The signal is attenuated per km
- Frequencies above a cutoff are strongly reduced
- Noise is added to the signal

Bandwidth

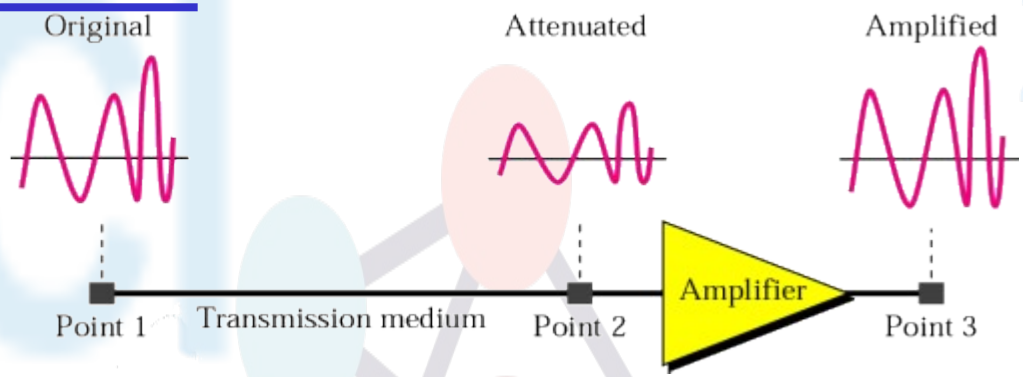


Signal impairments



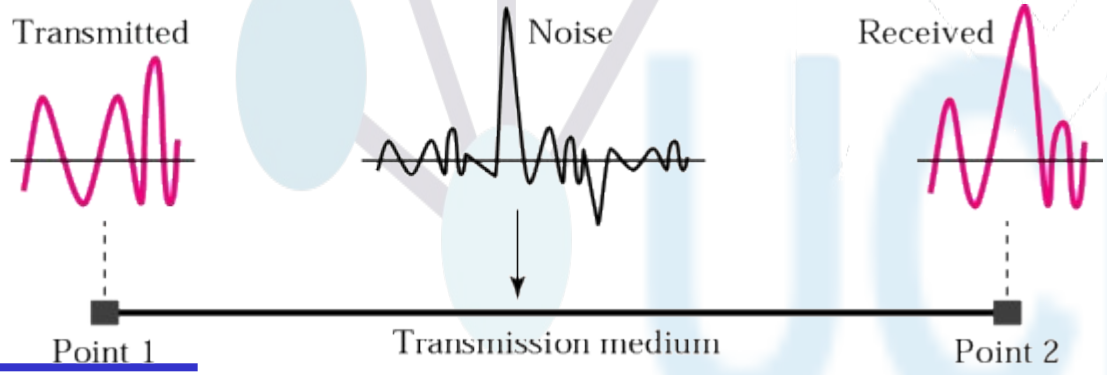
Signal distortion

attenuation

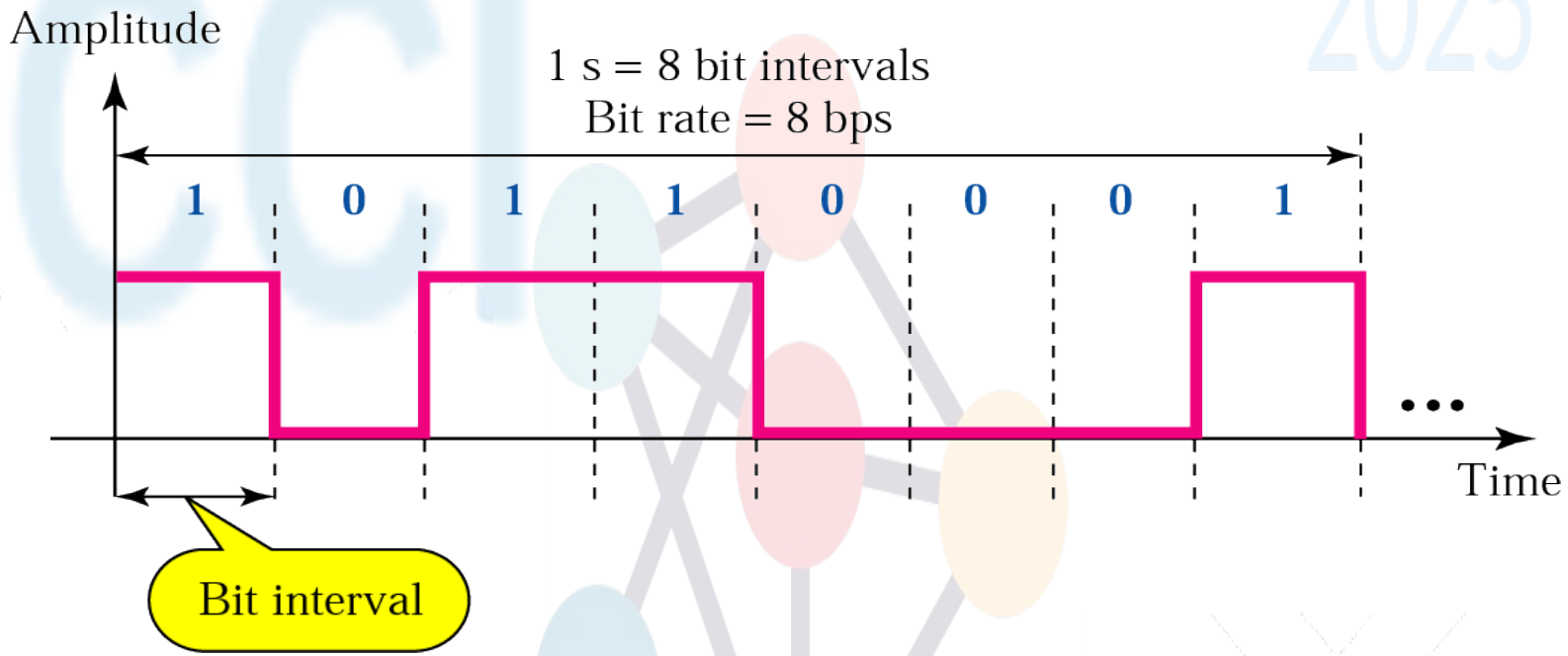


distortion

noise



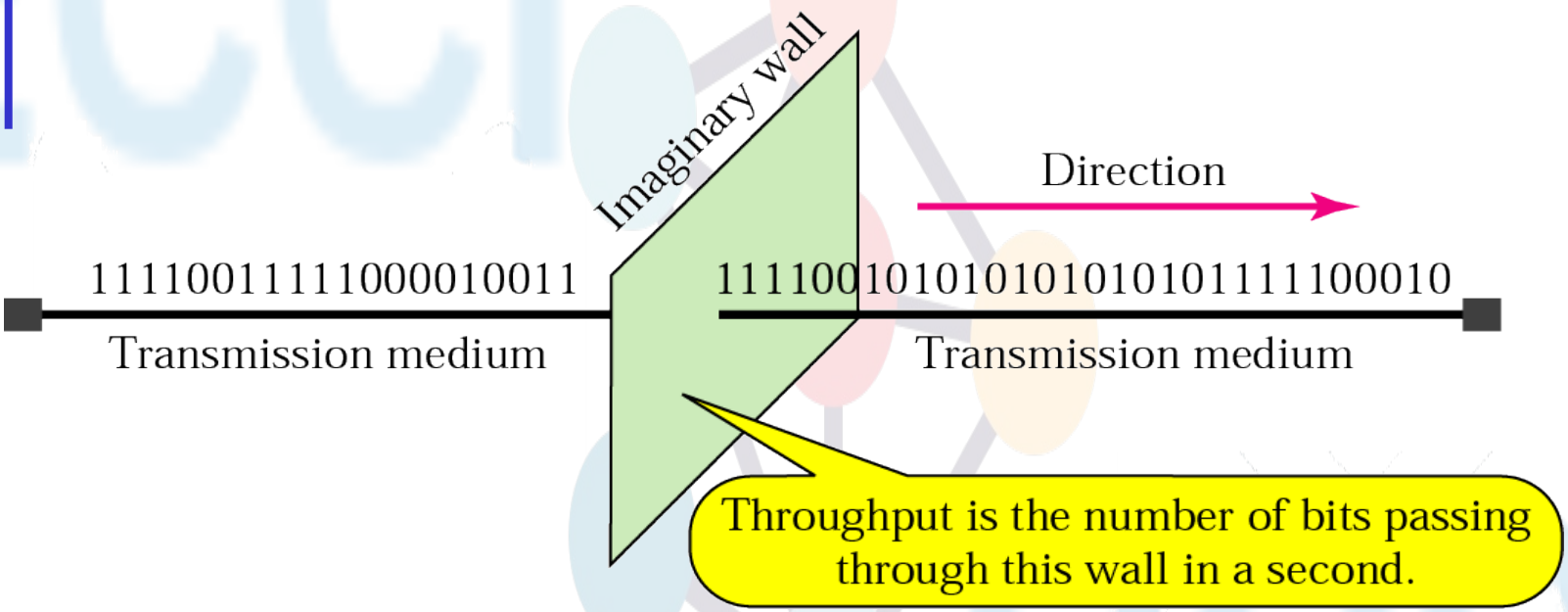
Digital signal



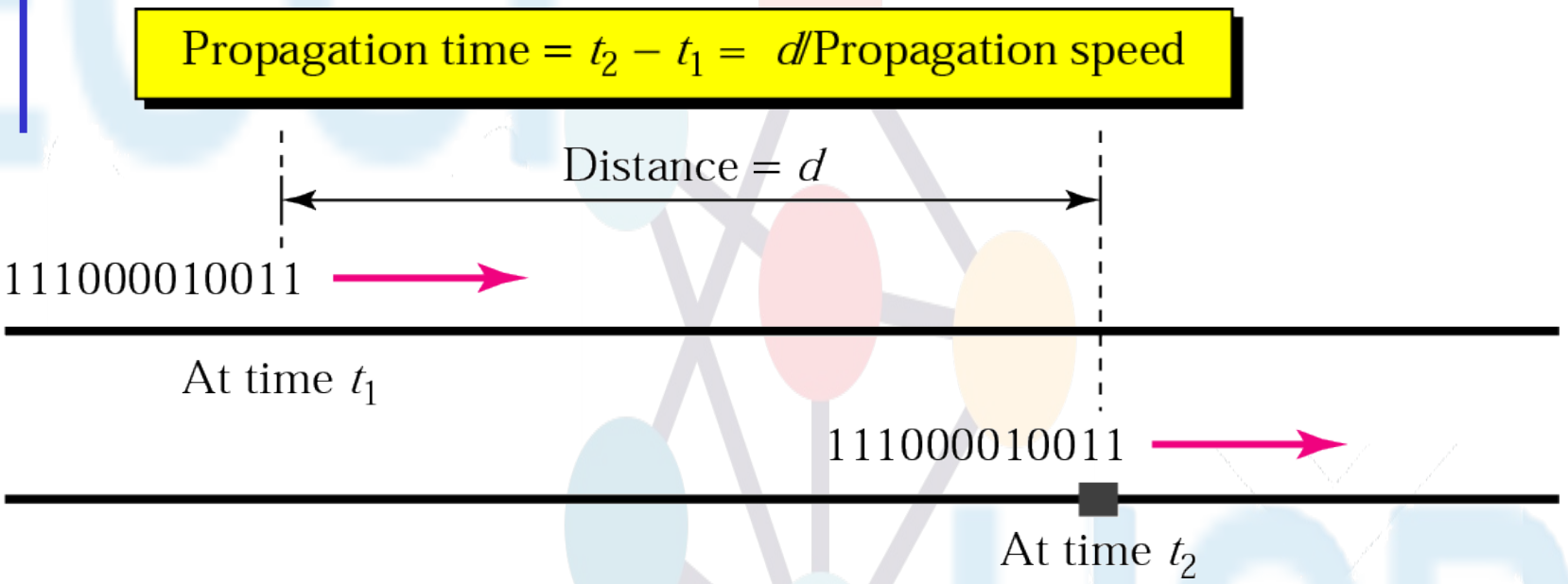
QUESTION:

What is the bandwidth of this signal?

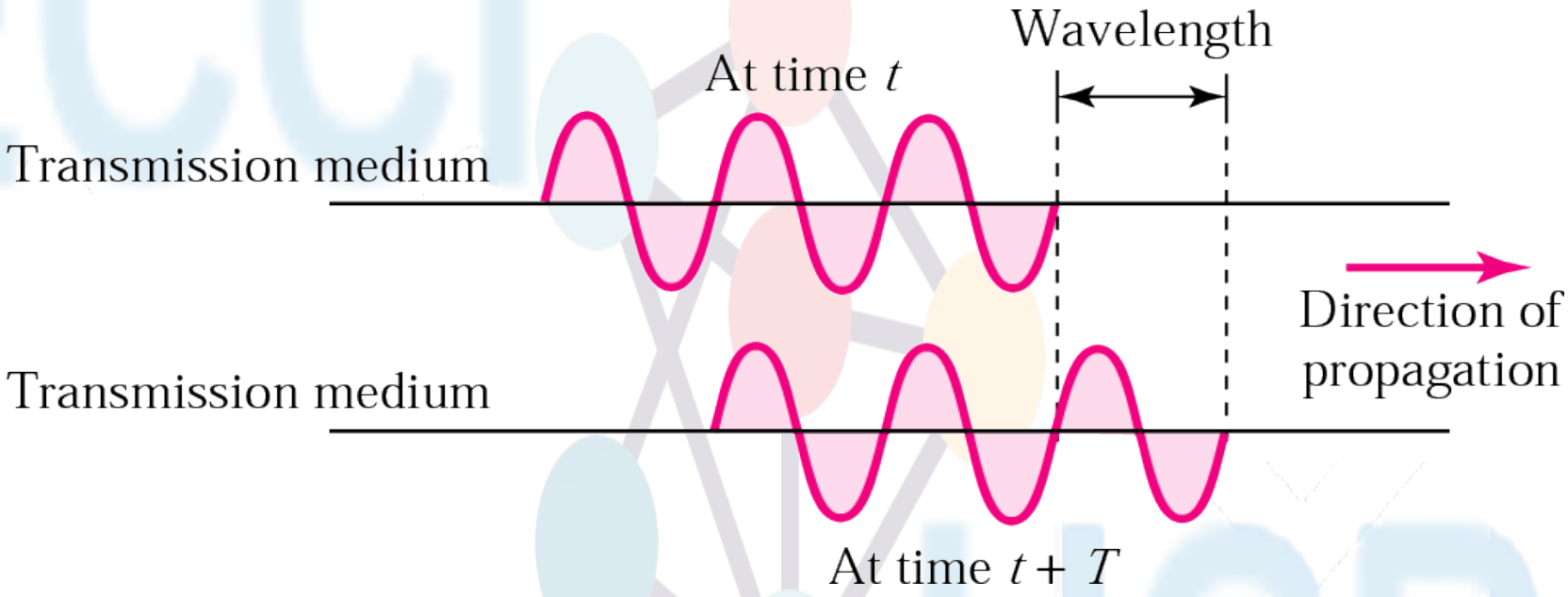
Throughput


Imaginary wall
Direction
11110011111000010011
Transmission medium
11110010101010101010111100010
Transmission medium
Throughput is the number of bits passing through this wall in a second.

Propagation time



Wavelength


Wavelength
At time t
Transmission medium
Direction of propagation
Transmission medium
At time $t + T$

Transmission media, persistent storage

- Examples: Bernie (Ch. 1 # 1)

Imagine that you have trained your St. Bernard, Bernie, to carry a box of three 8-mm tapes instead of a flask of brandy. (When your disk fills up, you consider that an emergency.) These tapes each contain 10 gigabytes. The dog can travel to your side, wherever you may be, at 18 km/hour. For what range of distances does Bernie have a higher data rate than a transmission line whose data rate (excluding overhead) is 150 Mbps? How does your answer change if

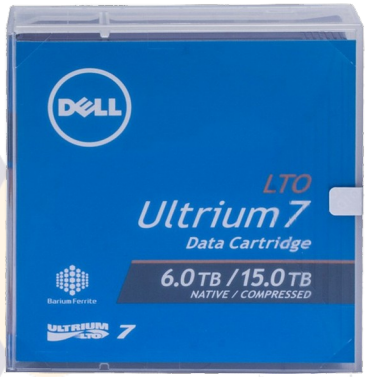
i) Bernie's speed is doubled

ii) each tape capacity is doubled

iii) the data rate of the transmission line is doubled.

Transporting Physical Media

- AST 1990: Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway.



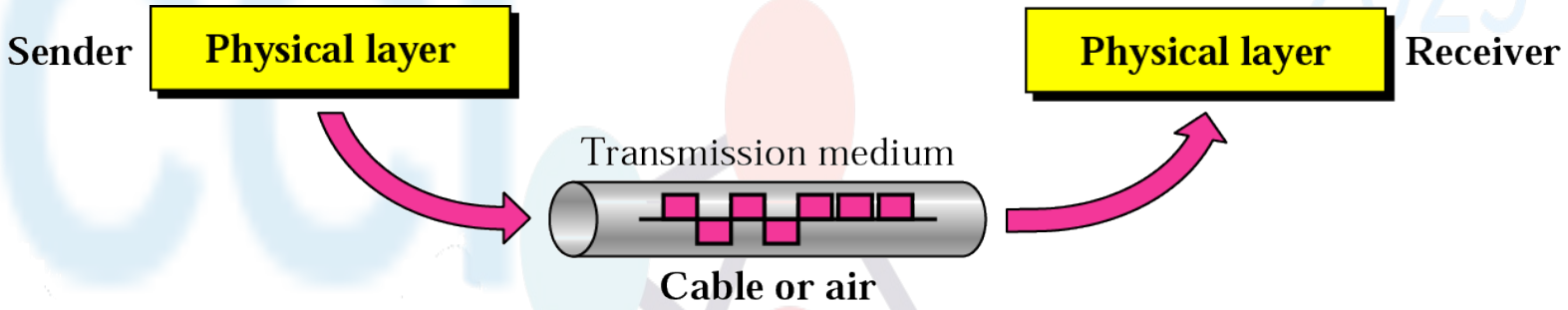
- Ultrium 7 tape = 6 TB, 400 cm^2 (costs €100)
- Typical van has capacity of 7×10^6 cm^2
- Van holds 17,500 tapes holding 105×10^{15} bytes
- One person can drive NYC to LA in 5 days = 4×10^5 s
- This is a bandwidth of 2 Tbps or 2000 Gbps

Amazon's Snowmobile Service

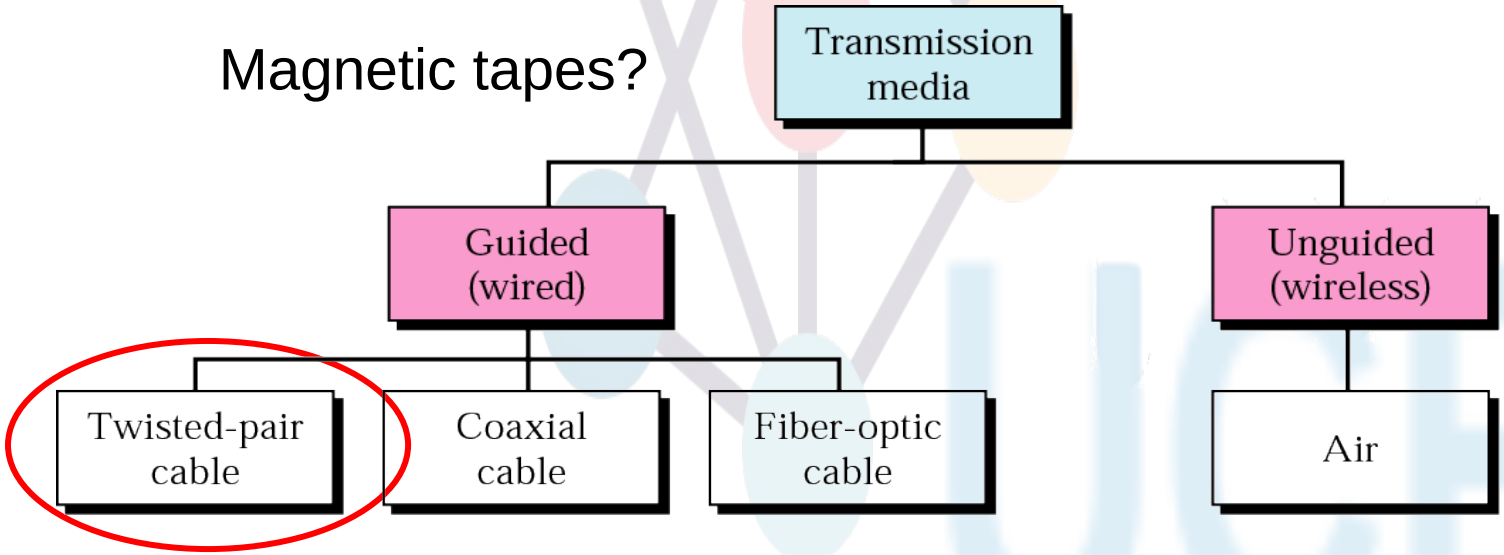
- When I first wrote that, I meant it as a joke
- No longer. Enter Amazon's Snowmobile service

- It is for companies to put their data in the cloud
- The Truck holds 100 PB (100,000 terabytes) on HDs

Transmission media



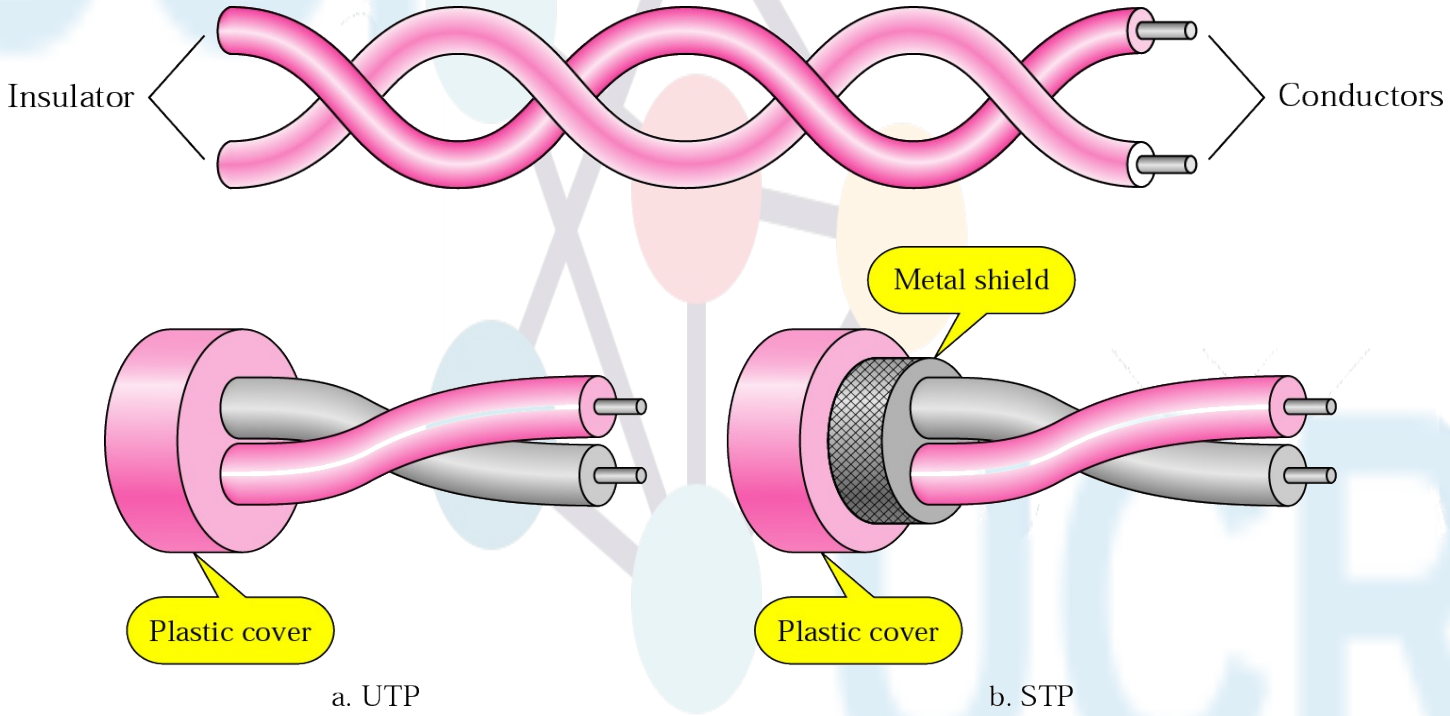
Magnetic tapes?



Twisted pair

Very common; used in LANs, telephone lines

- Twists reduce radiated signal (interference)
- UTP = Unshielded Twisted Pair



Twisted pair (cnt'd)

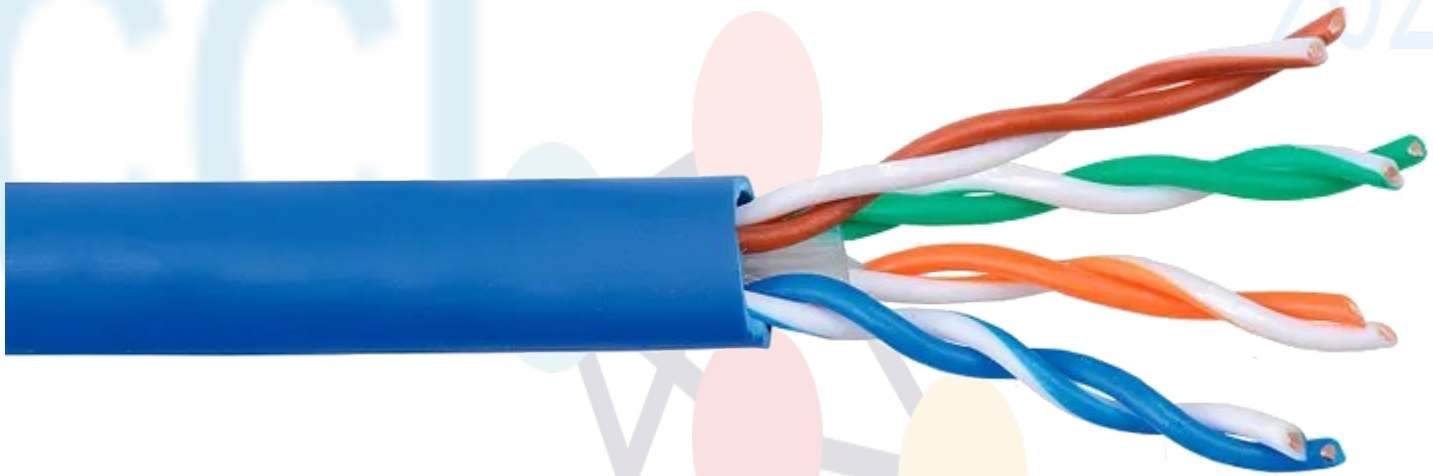


Fig. 2-1

Kinds of Wire

- STP = Shielded Twisted Pair
- UTP = Unshielded Twisted Pair
  - Cat 3: Home telephone lines
  - Cat 5: Fast Ethernet (100 Mbps)
  - Cat 5e: Gigabit Ethernet (1 Gbps)
  - Cat 6: 10-Gigabit Ethernet (10 Gps) up to 100 m
  - Cat 6A: Better quality Cat 6
  - Cat 7: Includes shielding (not in common use)

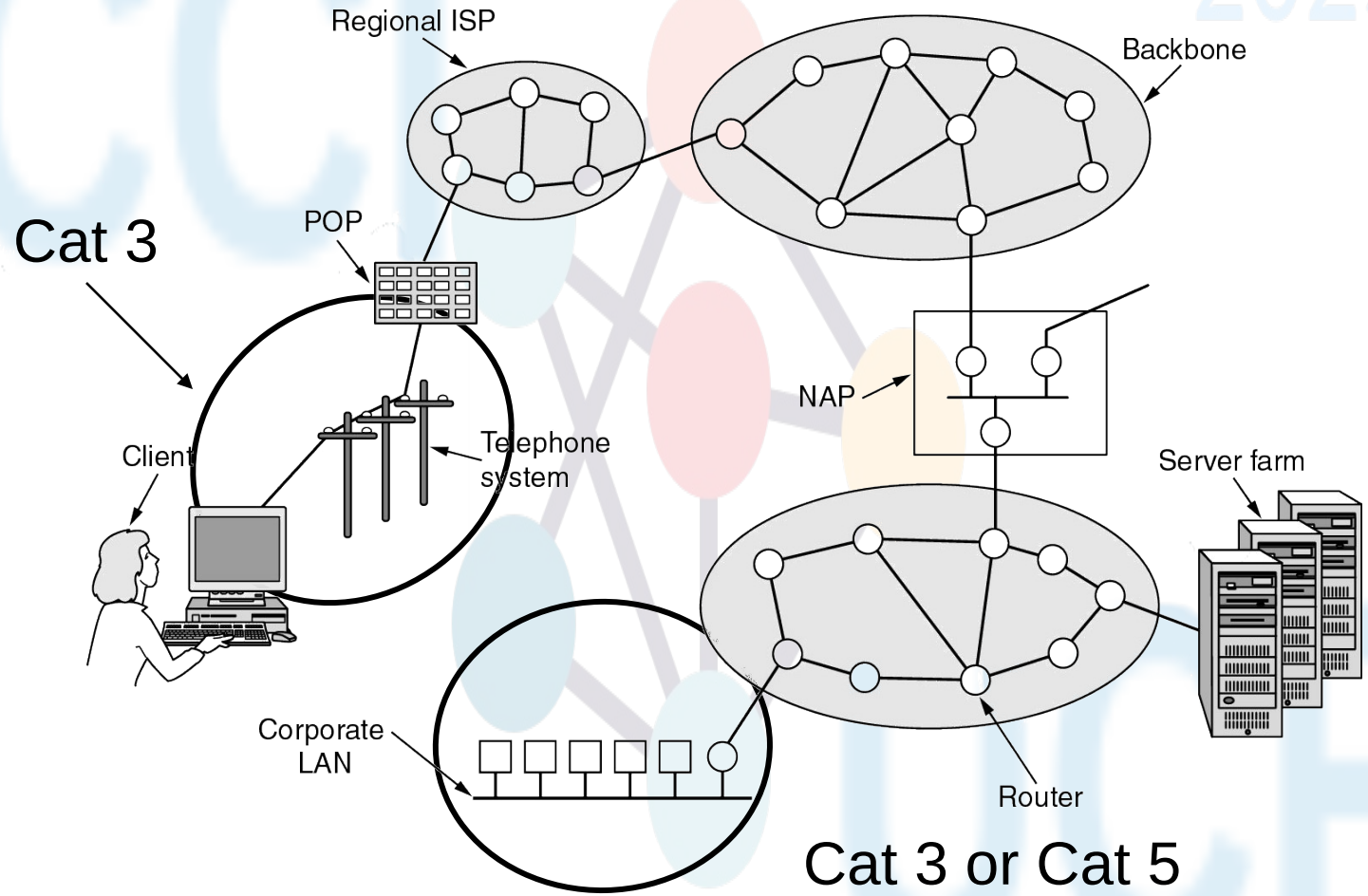
Connectors

RJ11 – 4 wires

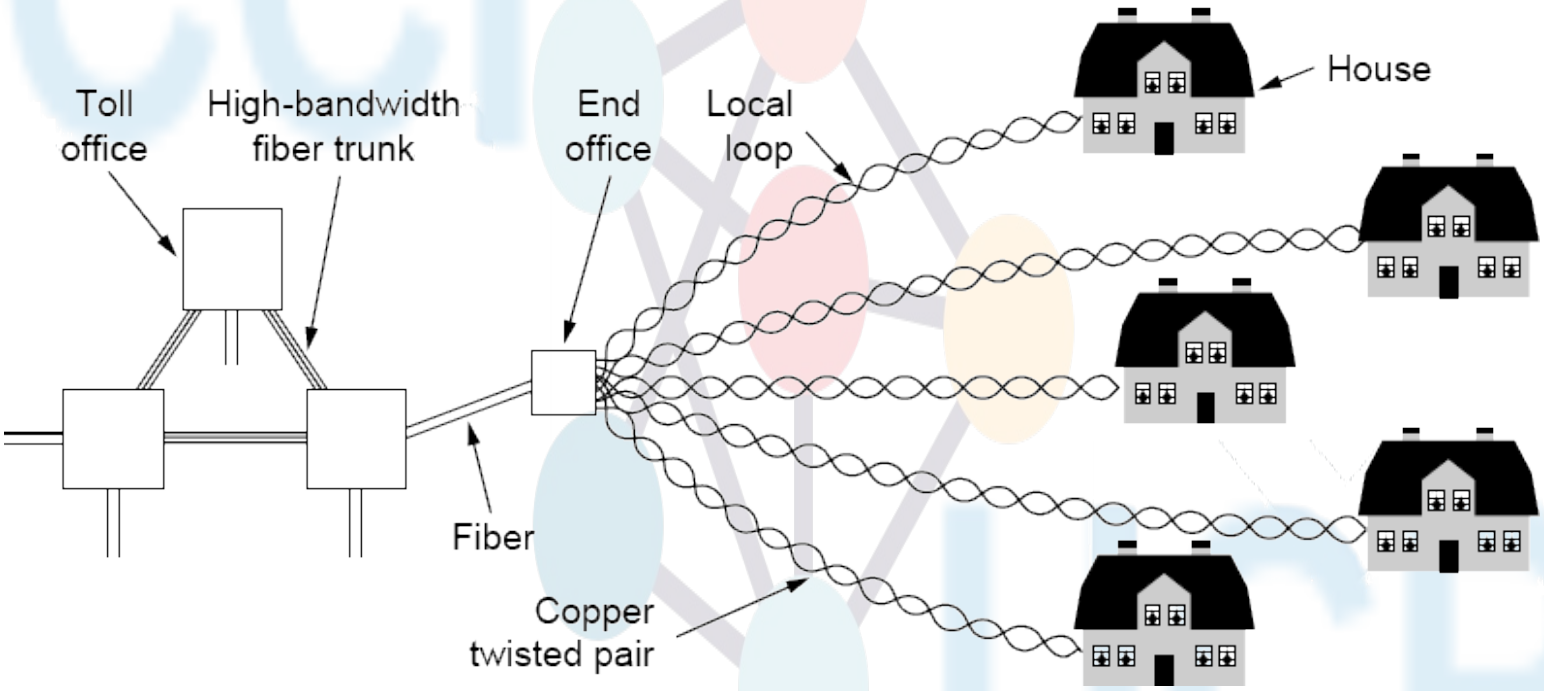
RJ45 – 8 wires

Modern buildings are wired for RJ45 but there are adapters

Using twisted pair cables in a network



Using twisted pair cables in a network (cnt'd)



Twisted pair networks

-example -

- **ADSL**
- **Ethernet networks**
  - 10BASE-T
  - 100BASE-TX
  - 1000BASE-T
  - 1000BASE-TX (Cat5e (enhanced))

Twisted pair
- pros and cons -

Pros:

- easy to understand
- mass production - low cost
- most widely used medium

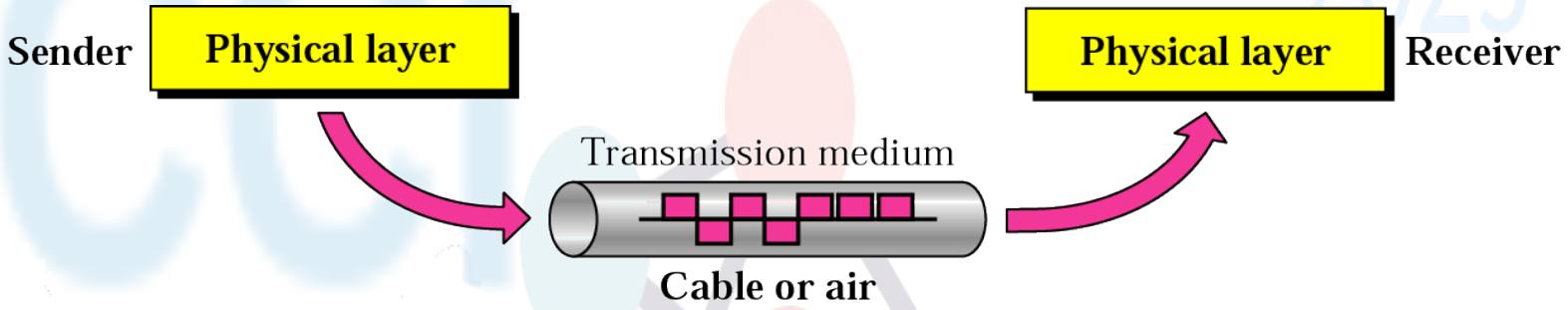
Cons:

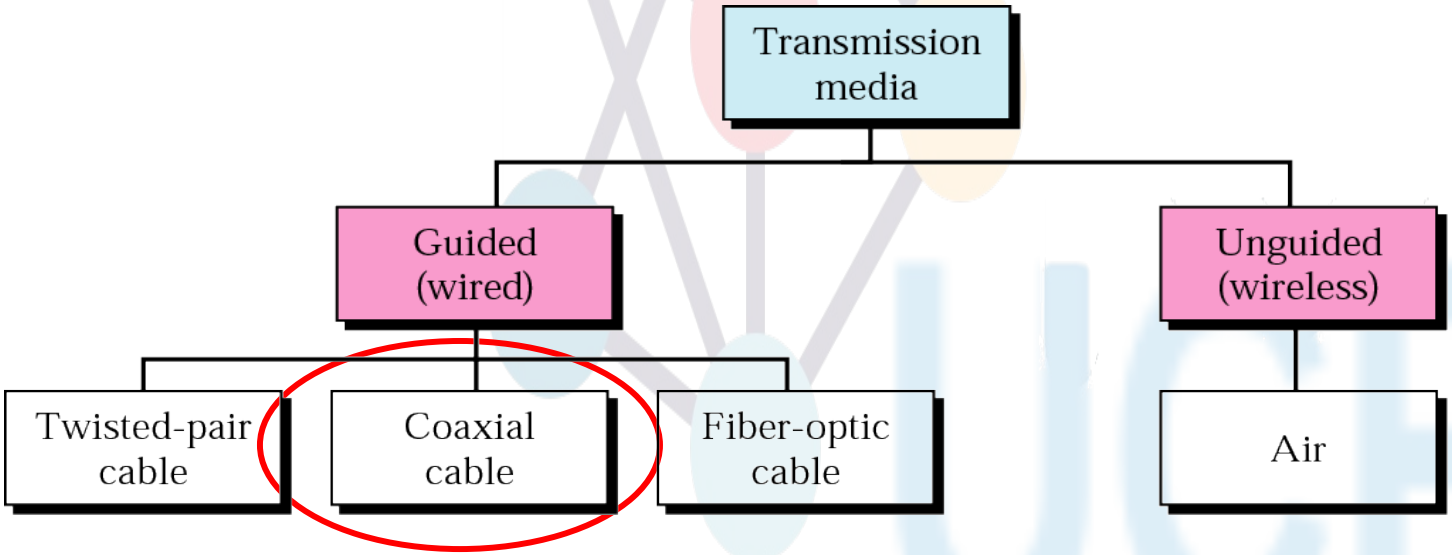
- prone to electromagnetic interference
  - in power plants, airport buildings, military facilities, cars…

Note:

In-building networks at our university are almost all twisted pair

Transmission media





Coax cable

Also common. Better shielding and more bandwidth for longer distances and higher rates than twisted pair.

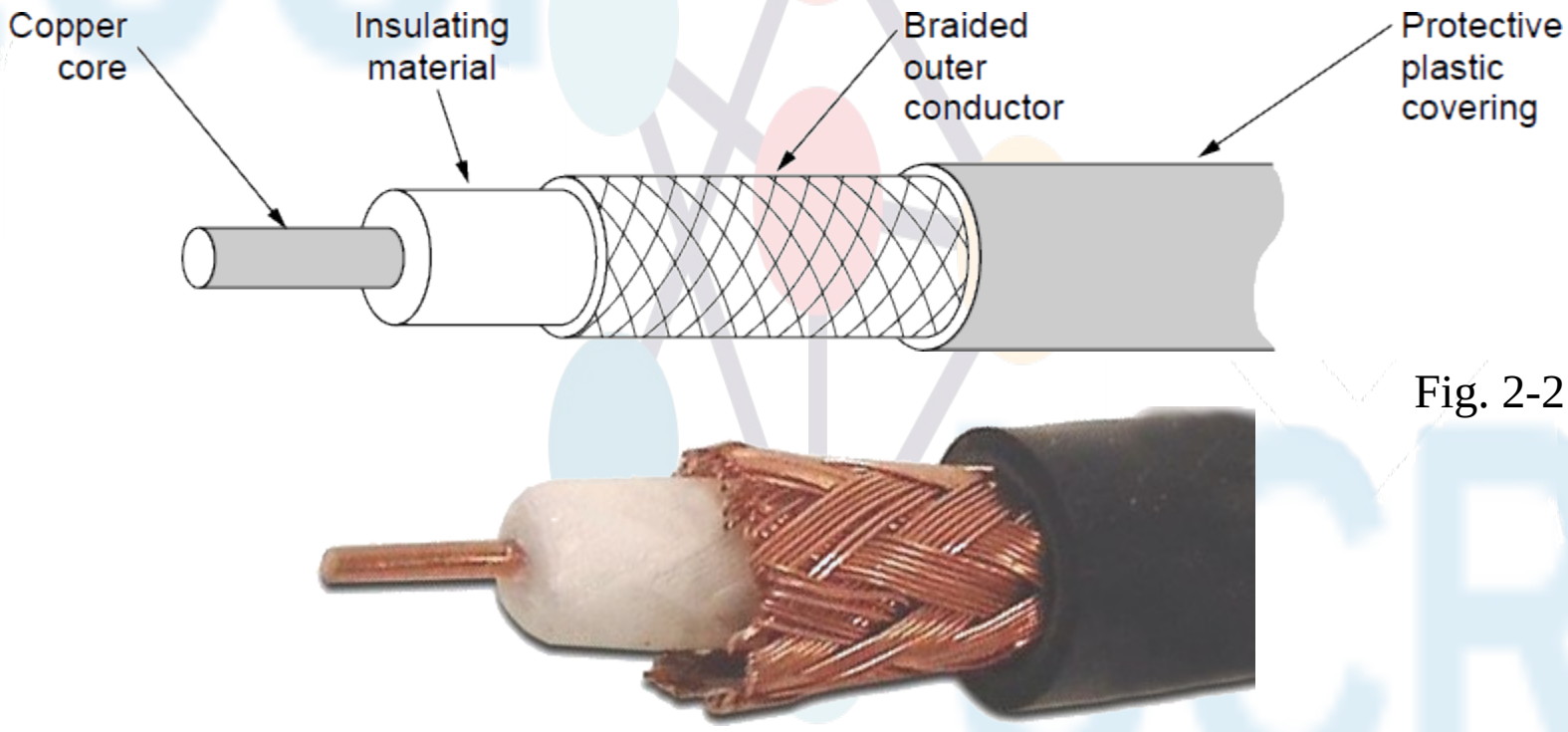
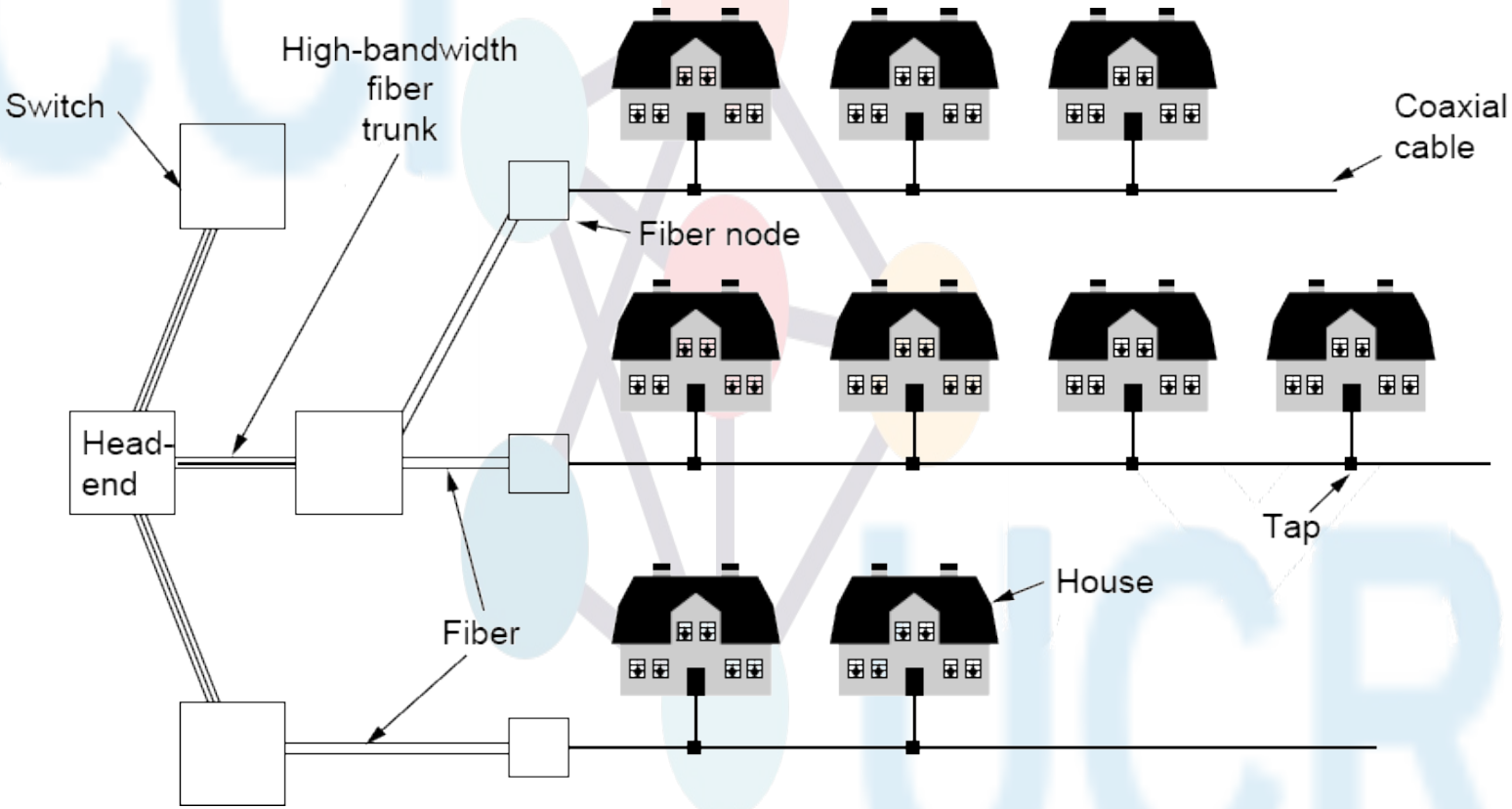


Fig. 2-2

Coax cable network
- example 2-

cable modem



Wires and power lines

Household electrical wiring is another example of wires

- Convenient to use, but poor for sending data

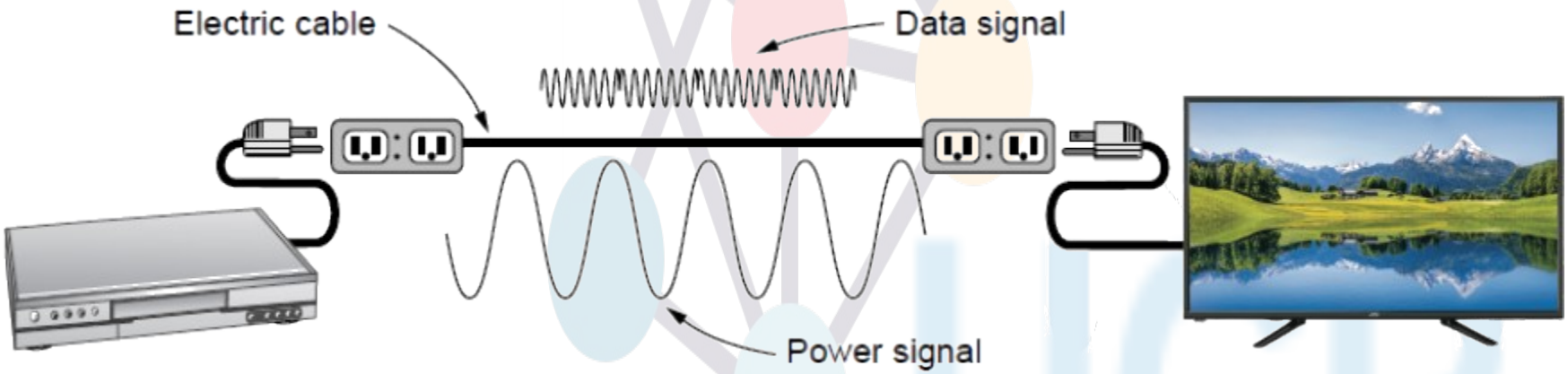
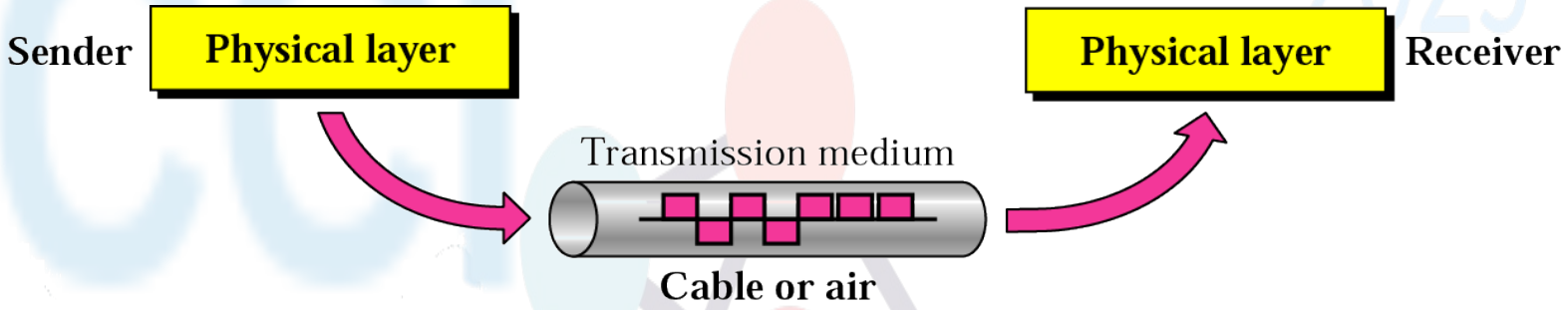
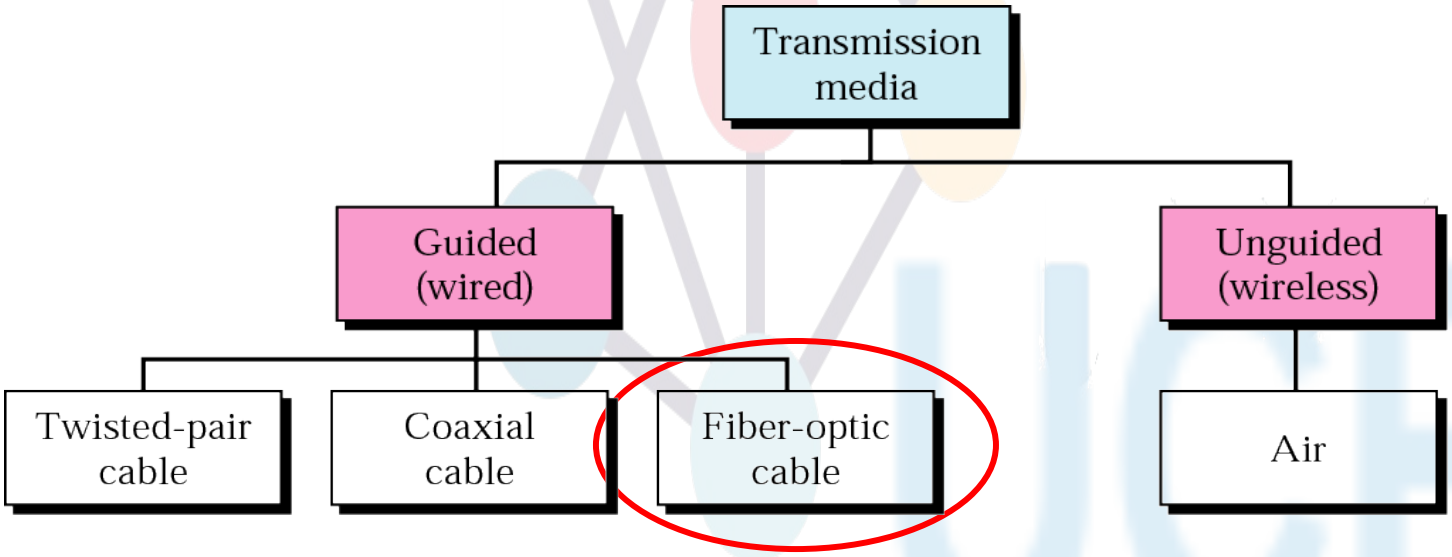


Fig. 2-3

Transmission media

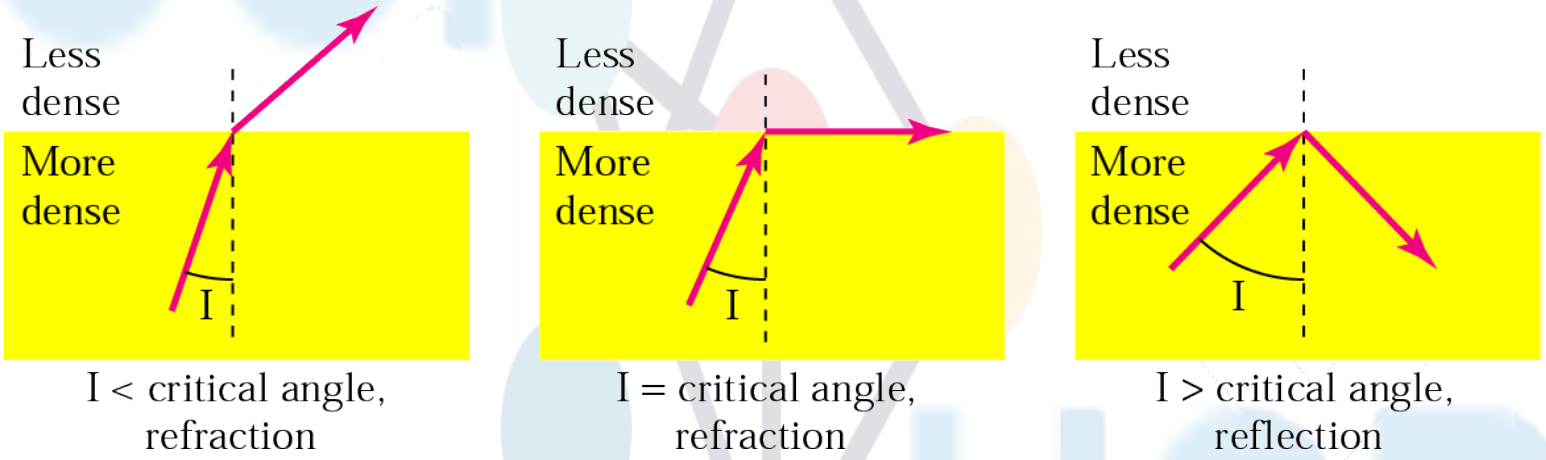




Optical fiber fundamentals

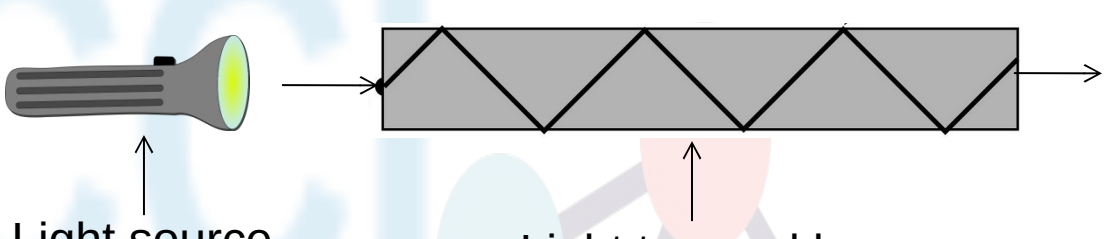
Banding the light ray

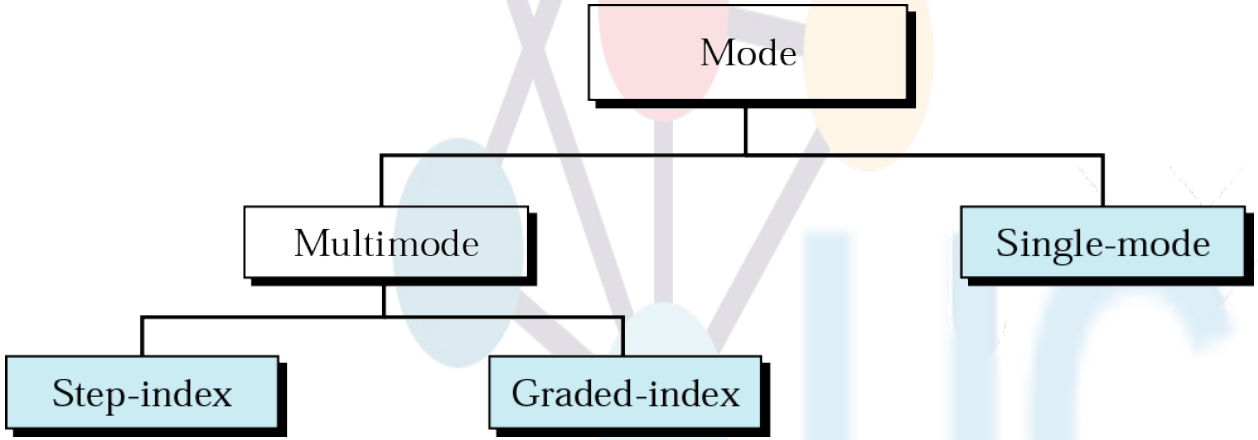
Fig. 2-4



Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

Optical fiber fundamentals





Optical fiber fundamentals

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

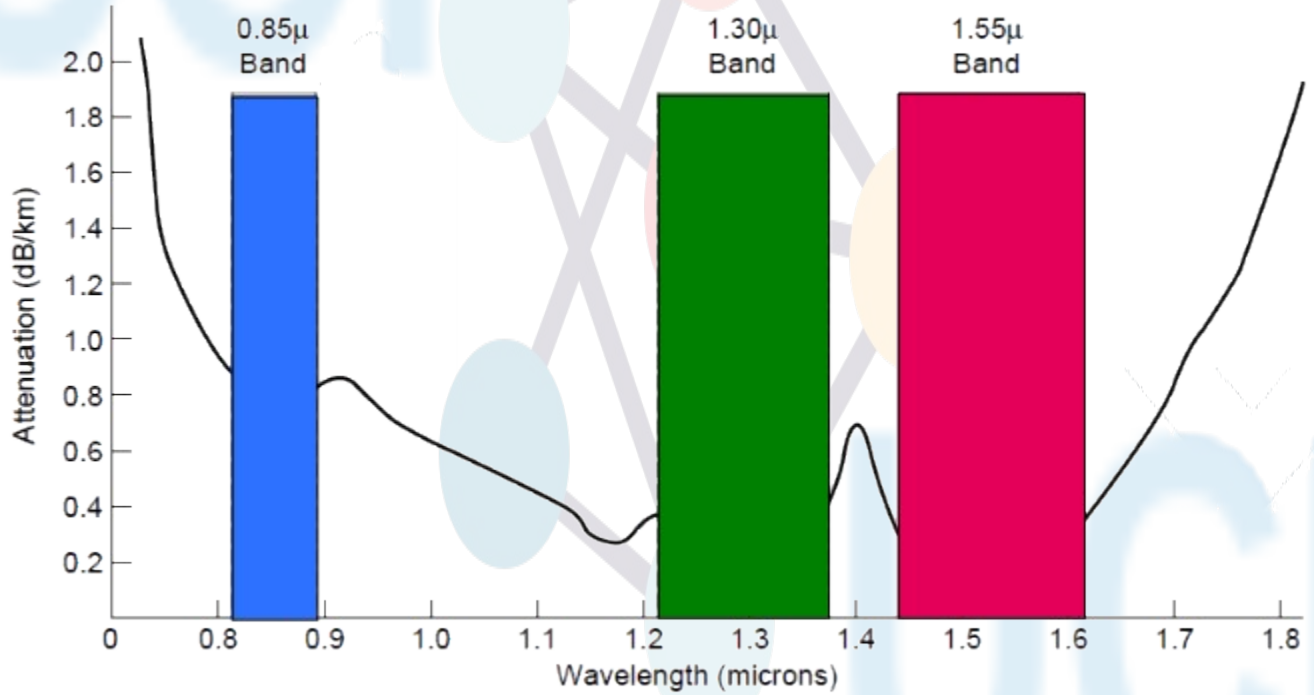
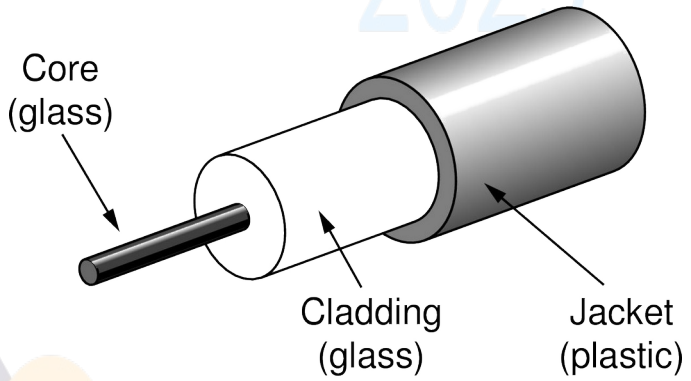


Fig. 2-5

Optical fiber fundamentals

Fig. 2-6

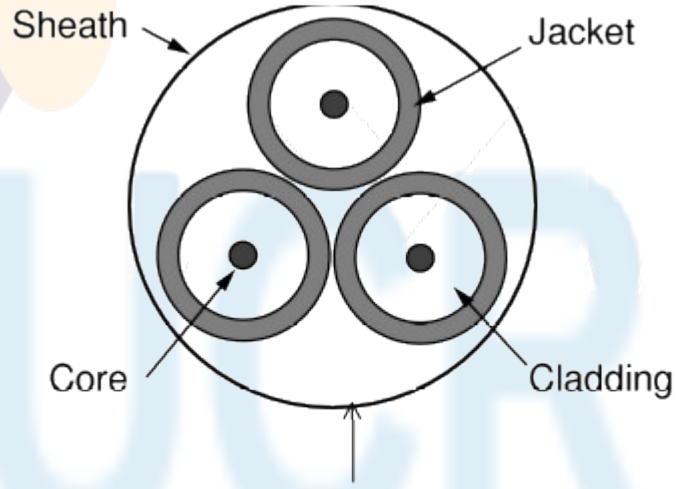


Single-mode

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

Multi-mode

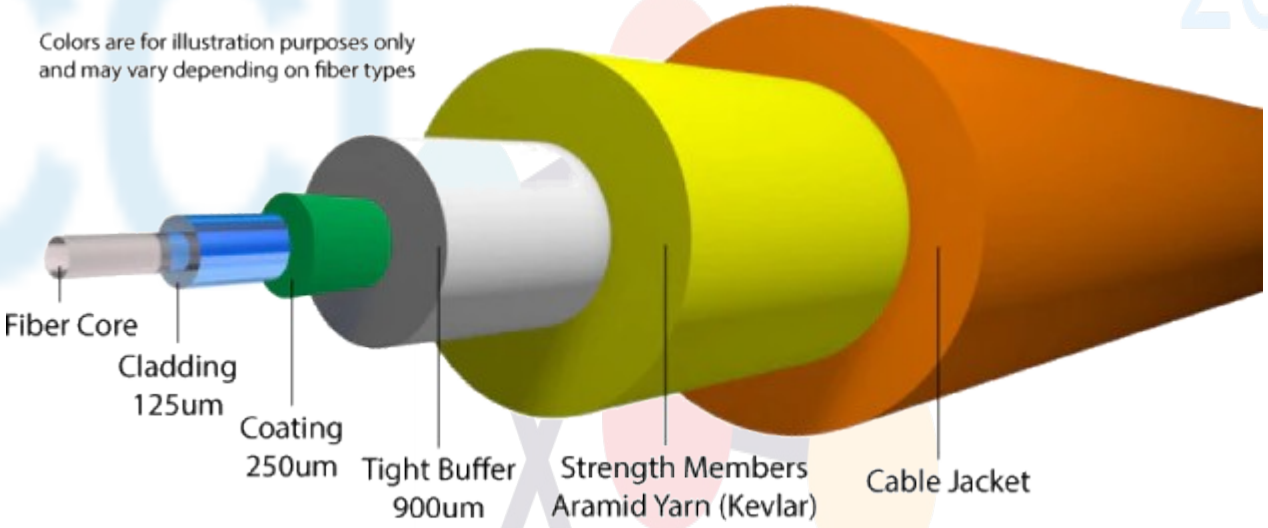
- Other main type of fiber
- Light can bounce (50um core)
- Used with LEDs for cheaper, shorter distance links

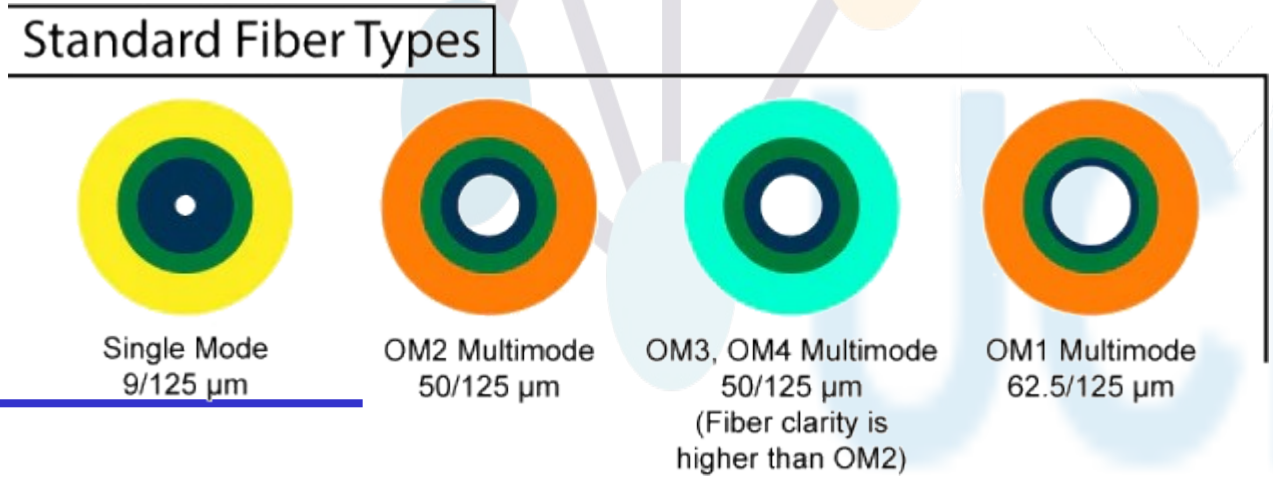


Fibers in a cable

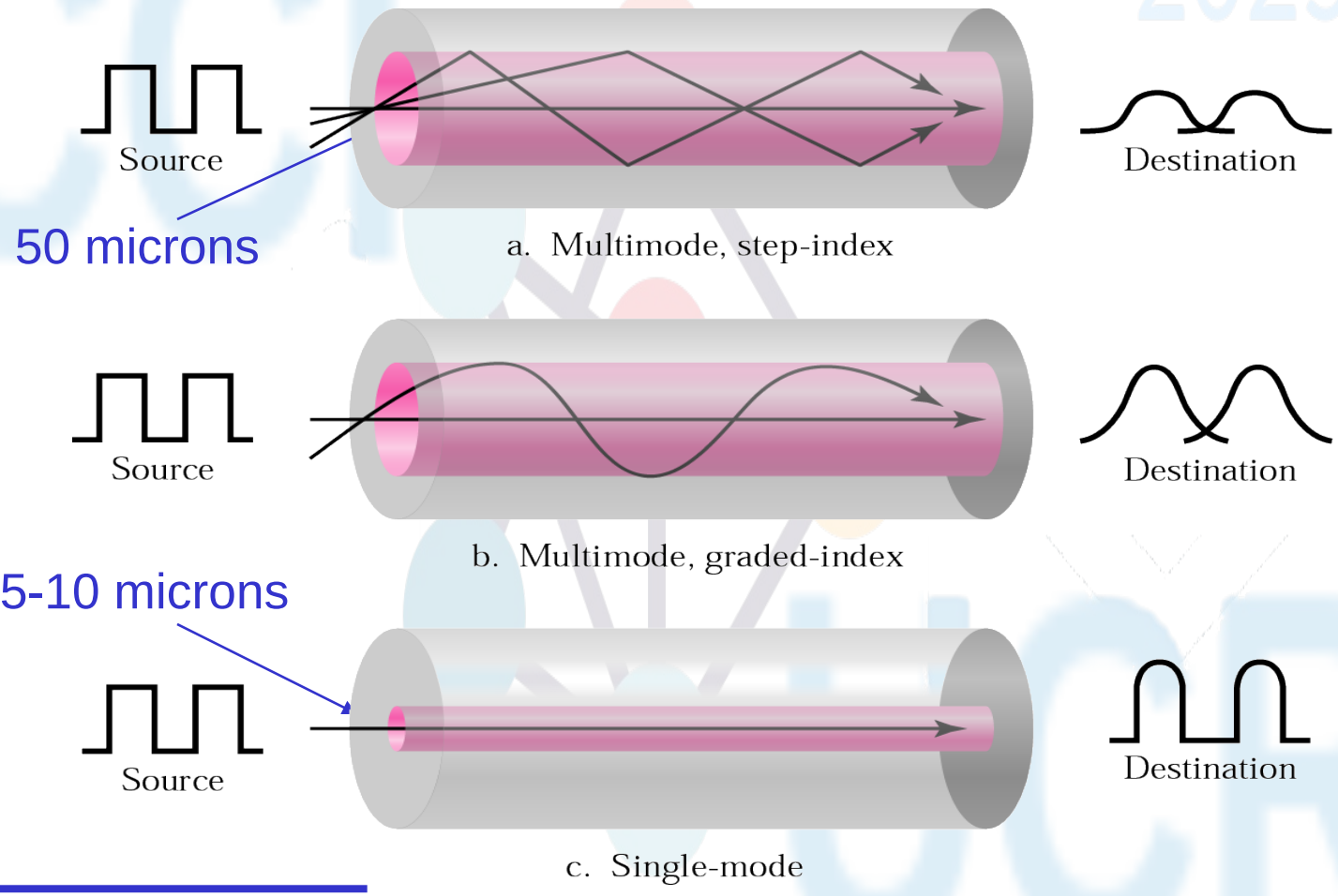
Optical fiber fundamentals

Fiber optic cable structures

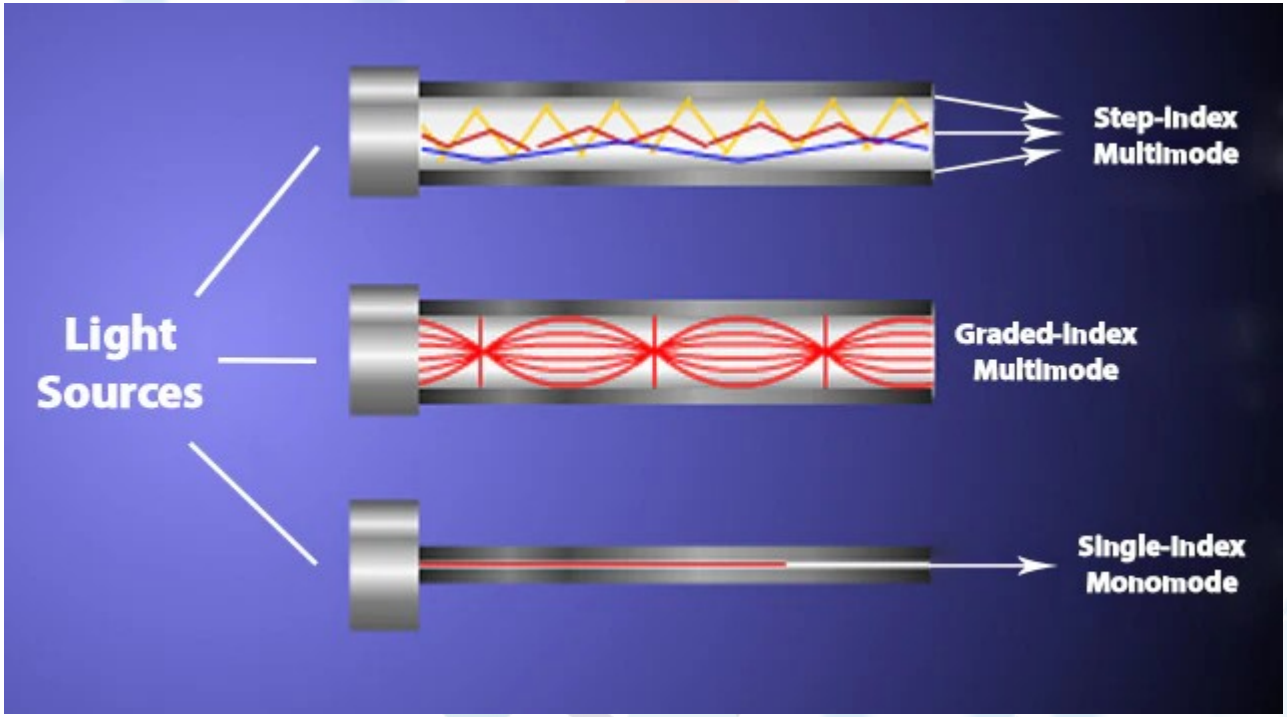




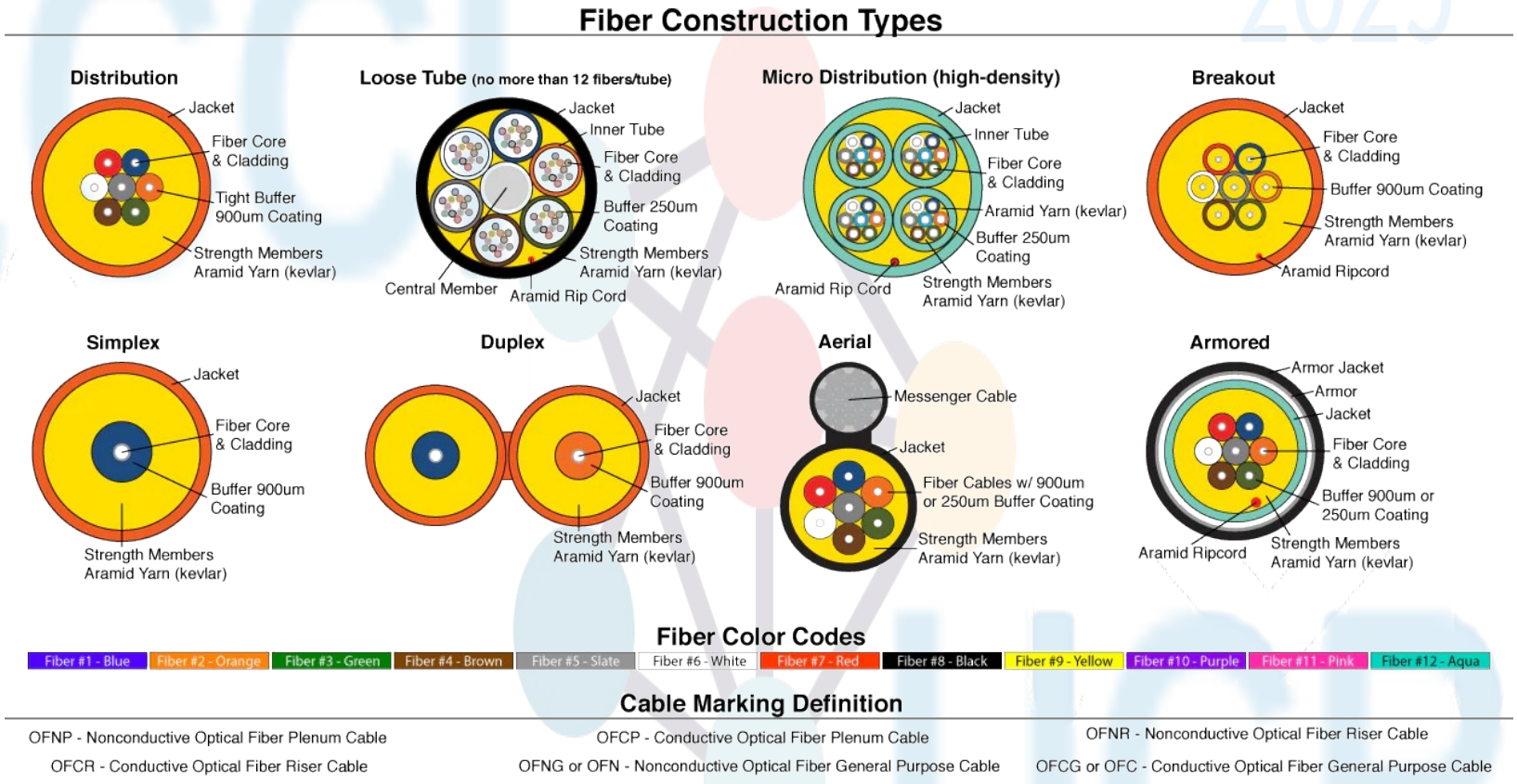
Optical fiber fundamentals



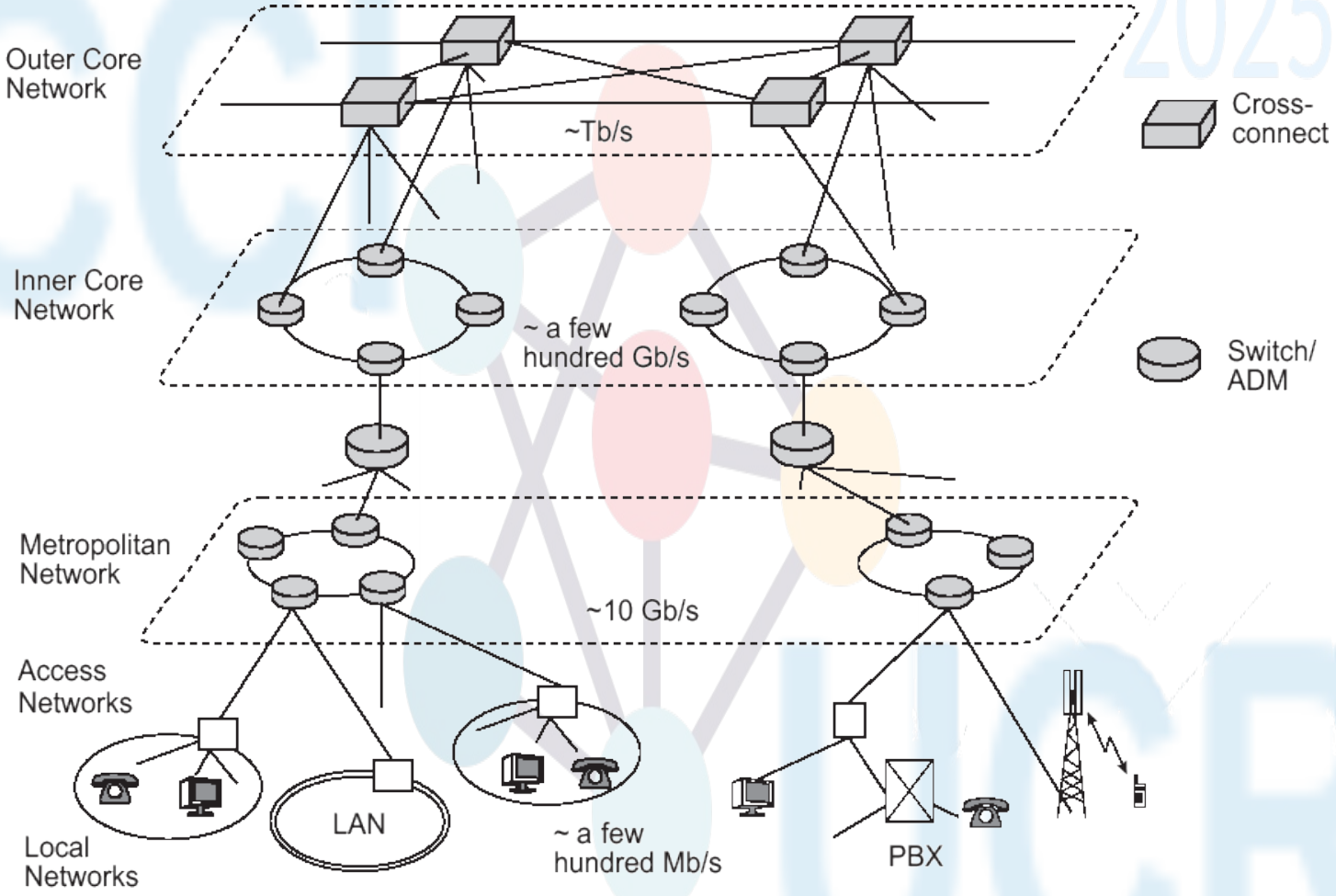
Optical fiber fundamentals



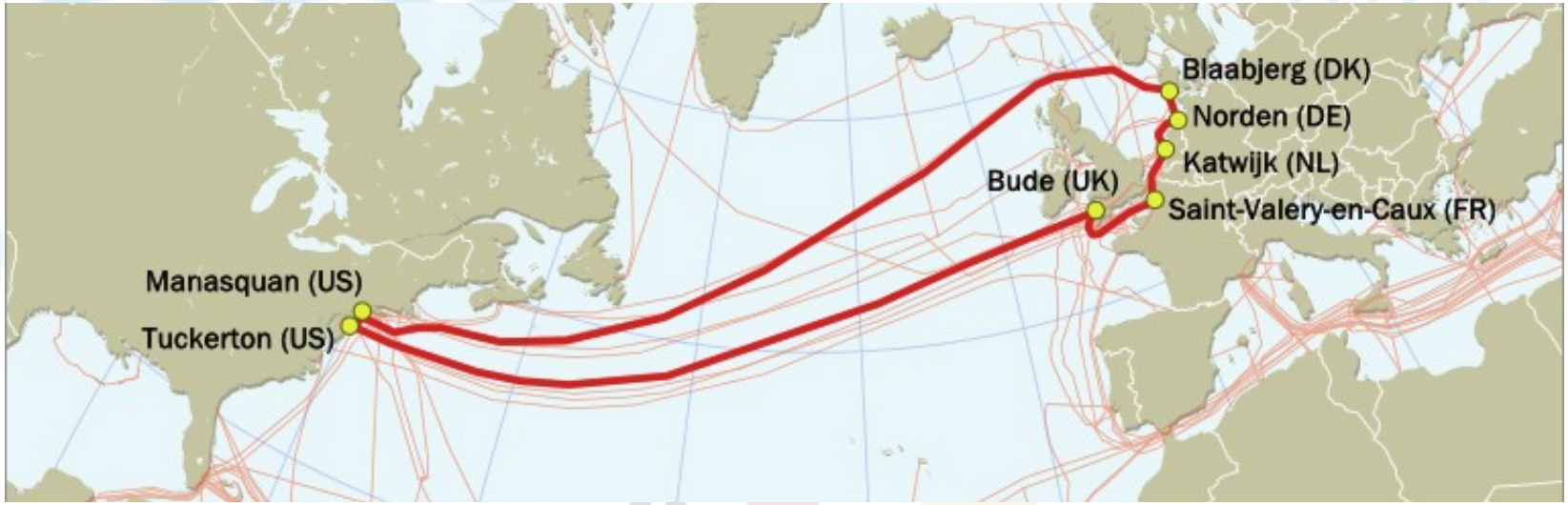
Fiber construction types



Optical fiber network
- example 1-



TAT-14 TransAtlantic Cable



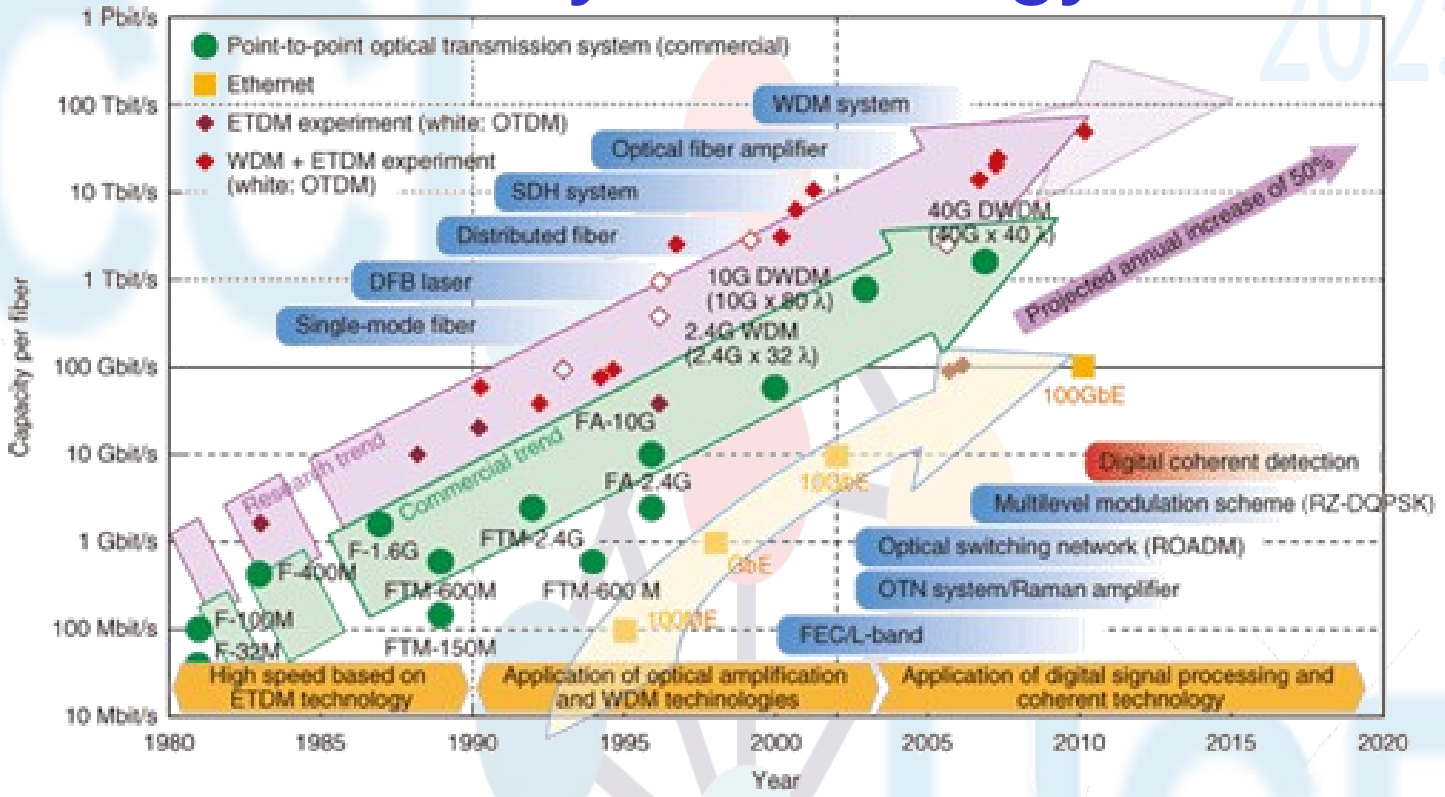
- Fiber cable lies on the ocean floor (8000 m deep)
- Ring structure
- Two pairs of fibers used plus two pairs for backup
- Theoretical capacity is 3 Tbps
- Cables are not well protected and there is no backup

Optical 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	Less cheap
Convenience	Easy to use	Less easy
Security	Easy to tap	Hard to tap

Bandwidth delivery capability by technology



100ME: 100-Mbit/s Ethernet
DFB: distributed feedback
F, FTM, and FA are the names of NTT systems.
FEC: forward error correction
G: Gbit/s
GbE: Gigabit (Gbit/s) Ethernet
λ: wavelengths

M: Mbit/s
ME: Megabit (Mbit/s) Ethernet
OTDM: optical time division reflectometry
OTN: Optical Transport Network
RZ-DQPSK: return-to-zero differential quadrature phase key shifting
SDH: synchronous digital hierarchy
WDM: wavelength division multiplexing

Conclusions

- Physical layer is the basis of all networks
  - limitations: attenuation, dispersion, noise, interference.
  - aims: provide
    - as much bandwidth and as larger span as possible
    - security
    - upgradeability @ low cost & protect investments, and
    - facilitate reconstruction of the transmitted signal

- Transmission media: guided