ELEN 90061
Communication Networks

Module 2 – Physical Layer

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Acknowledgement: these slides are a modified version prepared by Prof. Tansu Alpcan

Overview

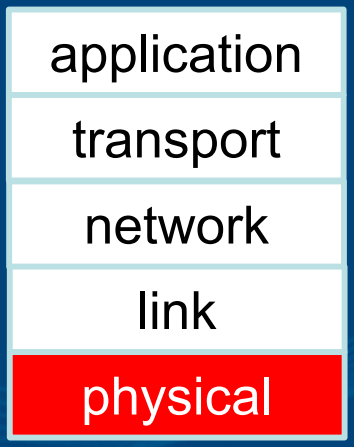
- Transmission media
  - Guided
    - Copper
    - Fiber optics
  - Unguided
    - Wireless Communications
    - Environmental effects
- Multiplexing
- Fundamental limits
- Example: Cellular Network
- Next generation communications

Suggested Reading

Note that there is overlap between these reading materials. It is a comprehensive list and you can use slides as a guideline for what to focus on.

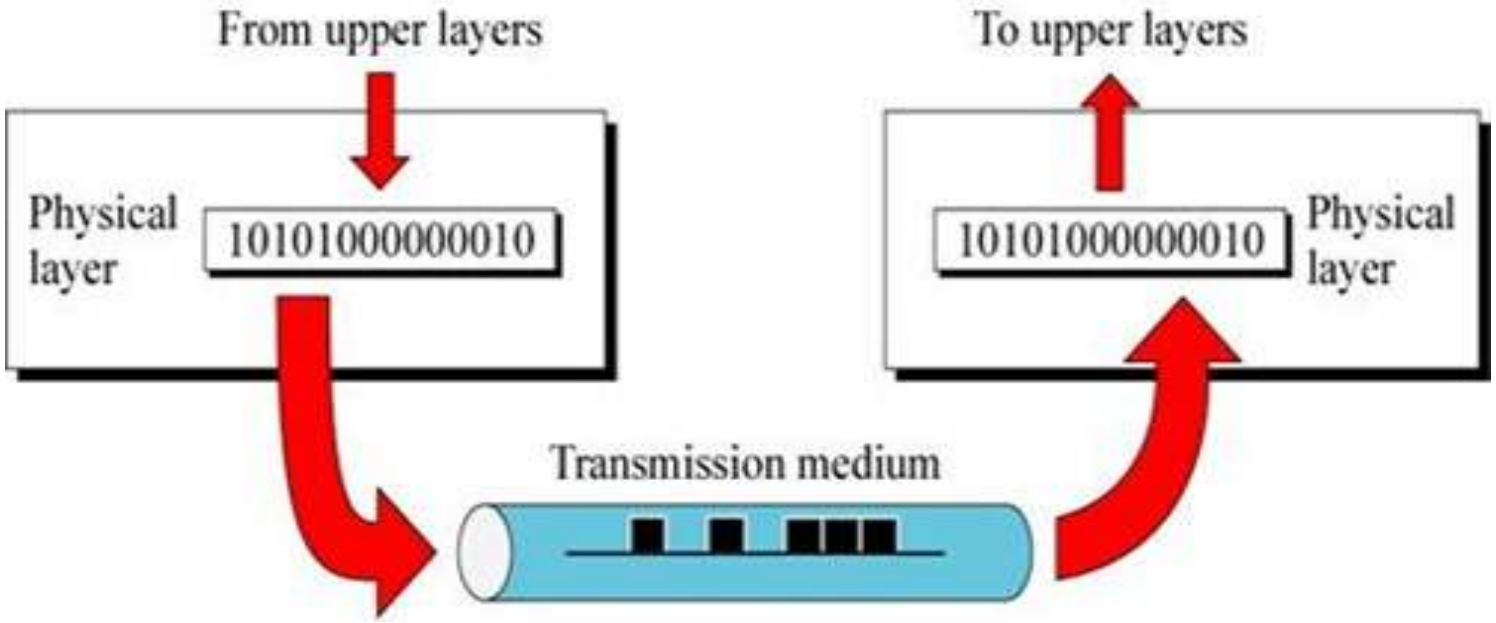
- Chapter 2 from Tanenbaum
- Chapter 1 from Kurose-Ross

Physical Layer

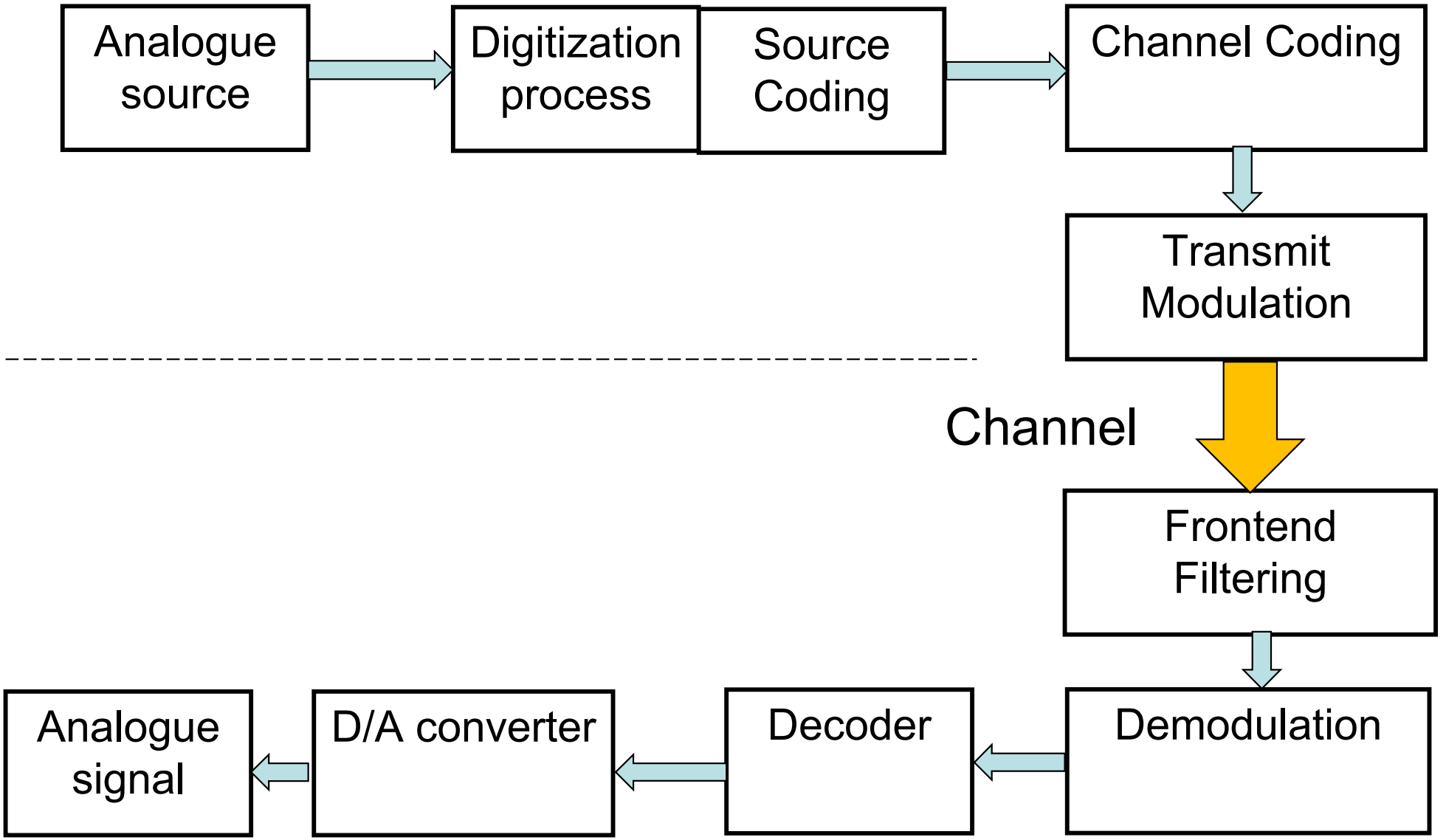


Physical Layer and Media

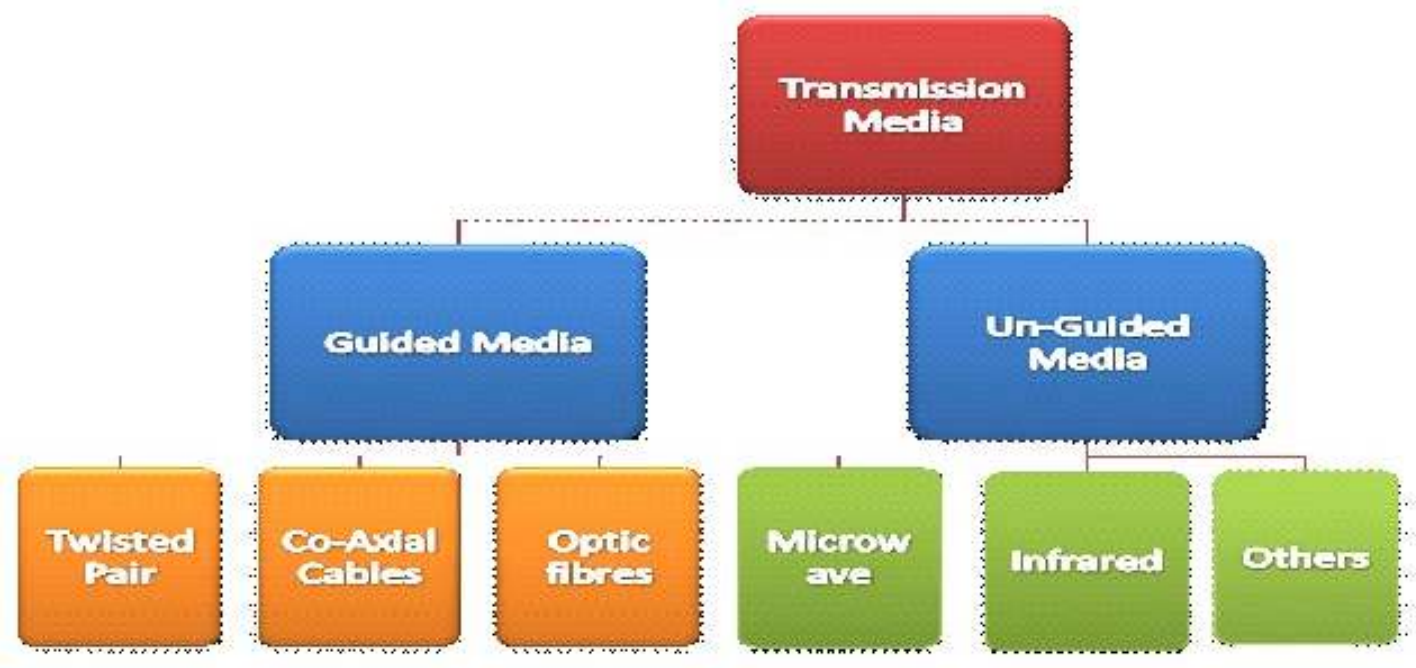
- Bits: propagate between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver



Physical Layer



Physical Layer and Media



- guided media:
  - signals propagate in solid, controlled media: TP copper wire, fiber, coax cable
- unguided media:
  - signals propagate freely, e.g., radio

Guided Transmission Data

Magnetic, optical Media; solid-state drives (SSD)

- Solid-state storage stores digital information using non-volatile electronic circuits

Tanenbaum:
Never underestimate the bandwidth of a station wagon full of tapes (drives) hurtling down the highway.

Real Life Example:

Amazon Snowball
- 80 terabytes of data delivery 24hr by courier service
- 25kg box

Effective bandwidth = 0.926 Gbps

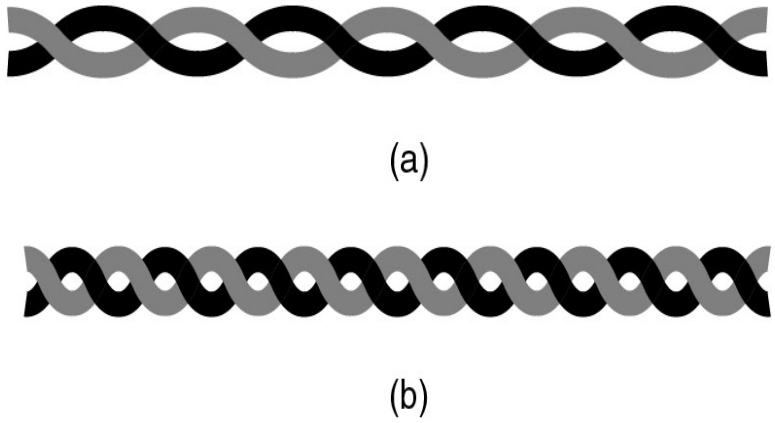
Question: in one word, what is the disadvantage of this method from a communications perspective?

Physical media: Twisted Pair

Twisted Pair (TP)

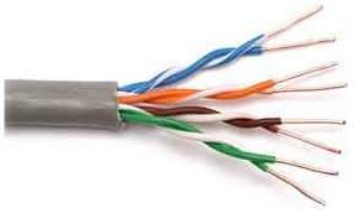
- two insulated copper wires
  - Category 3: phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps, 1Gbps Ethernet
  - Category 6: 10Gbps
- Used in telephone systems, ADSL, Ethernet

Question: why is the twisted pair twisted?



(a) Category 3 UTP.
(b) Category 5 UTP.

UTP: Unshielded Twisted Pair

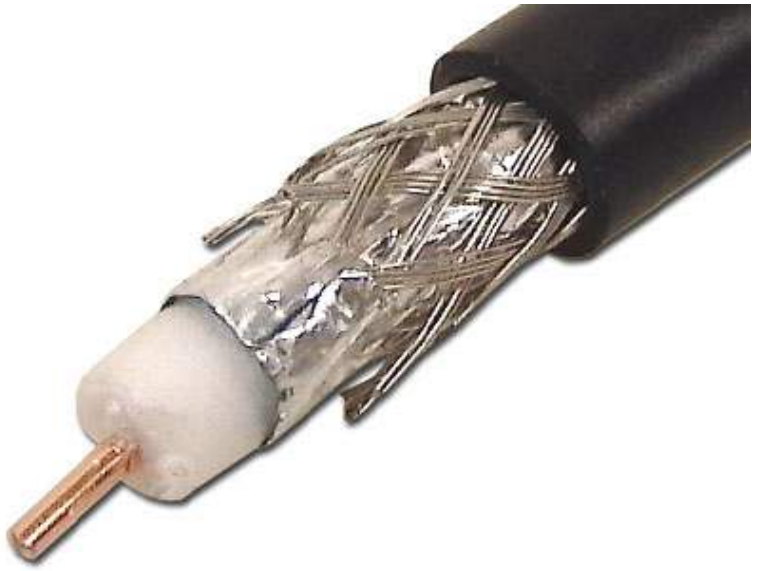


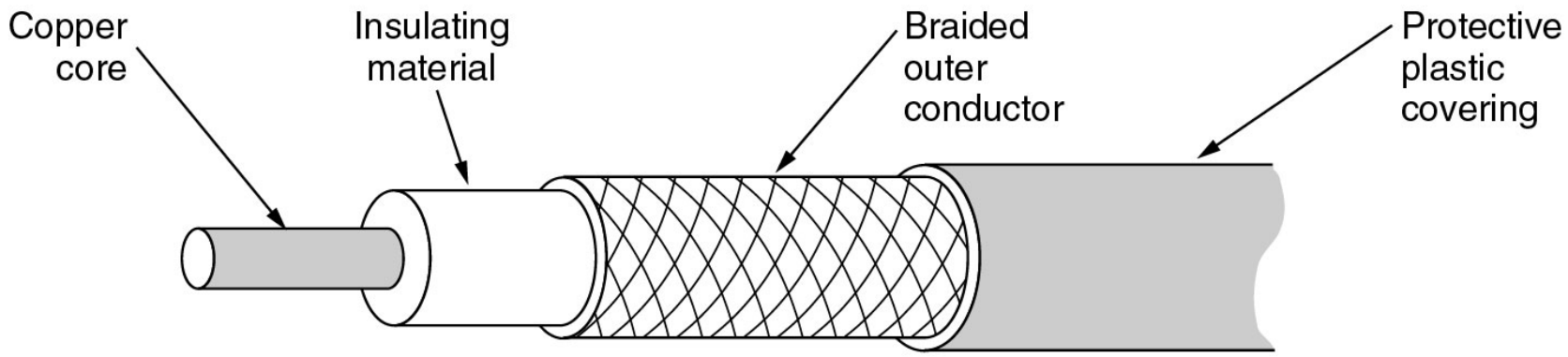
UTP Cable

STP Cable

Coaxial cable

- two concentric copper conductors
- Higher bandwidth than UTP
- broadband:
  - Multiple channels on cable
  - **HFC** (Hybrid fibre coax)
- Used for cable TV, Internet



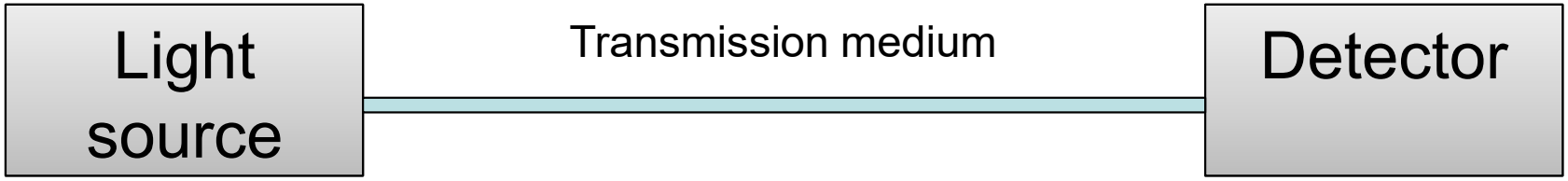


Physical media: Fiber Optic

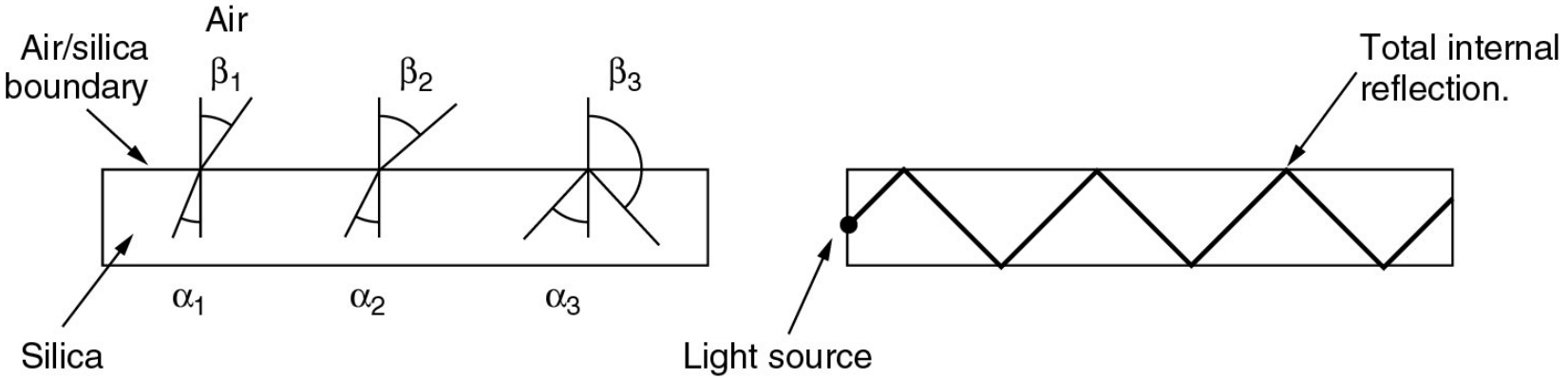
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise
- Costly

Fiber Optic Cable

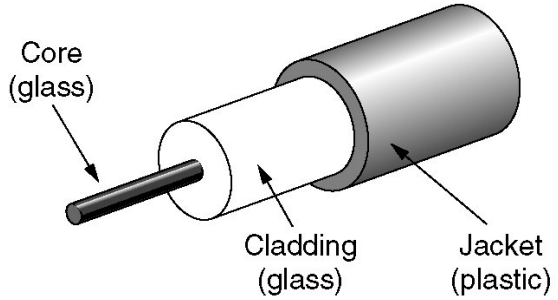
- glass fiber carrying light pulses



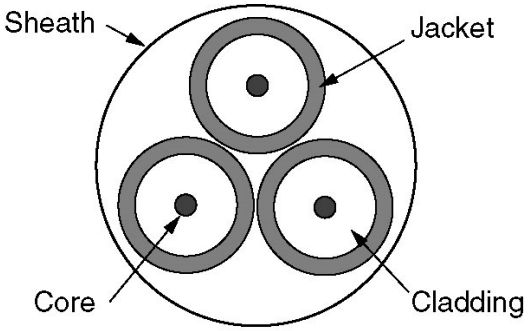
- A pulse of light indicates 1 bit, and the absence indicates a 0 bit.
- Detector generates an electric pulse when light falls on it.



Fiber Cable

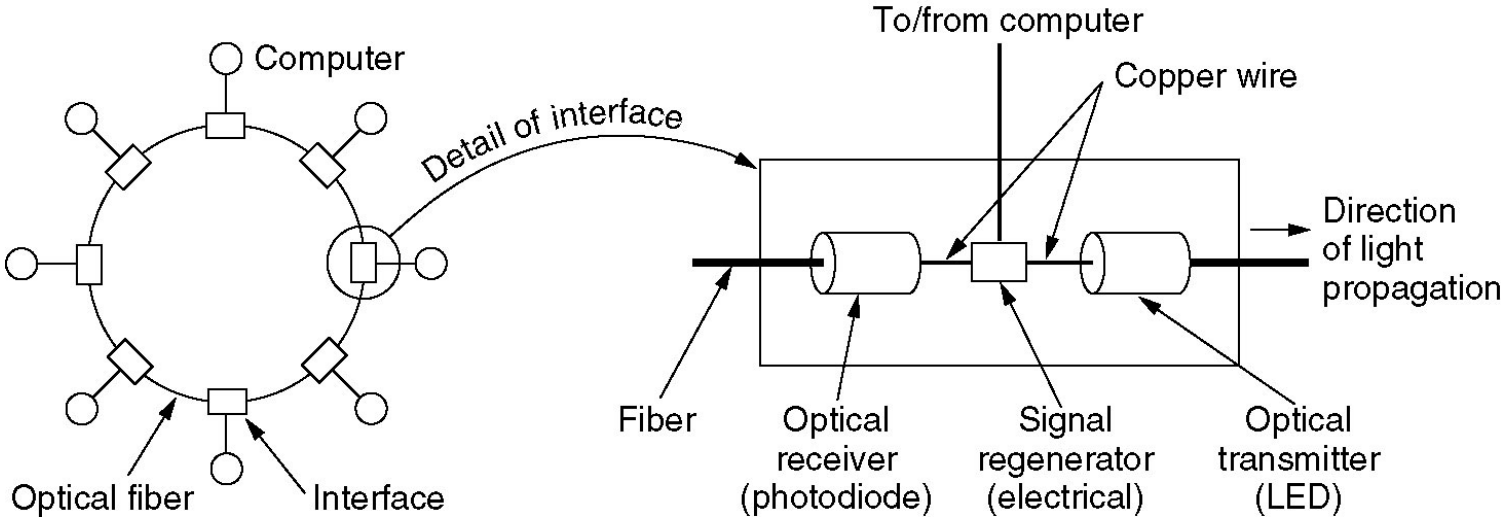


(a)



(b)

A fiber optic ring with active repeaters.



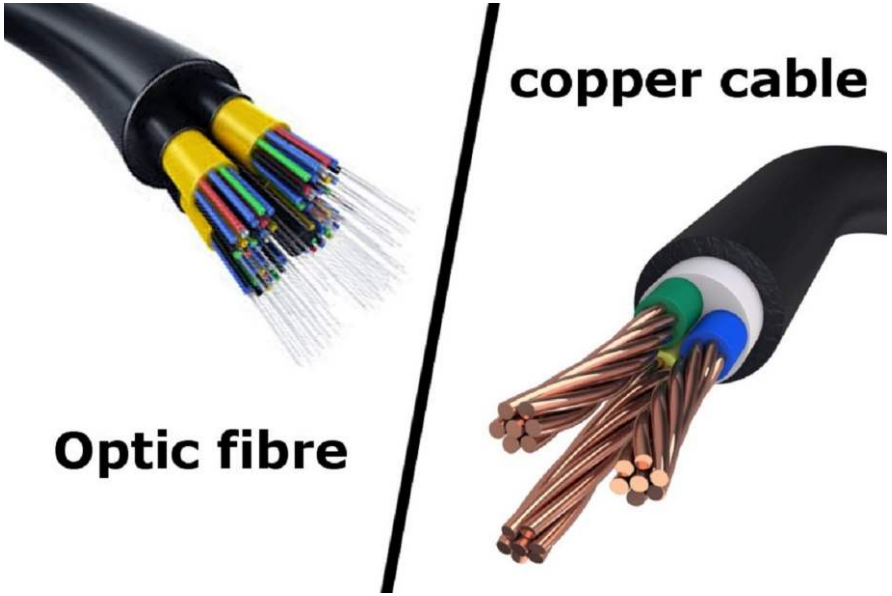
Fiber Optics versus Copper Wire

Fiber

- Higher bandwidth
- Low attenuation
- Not effected by EM interference
- Not effected by corrosive chemicals in the environment
- Thin and lightweight
- Difficult to tap

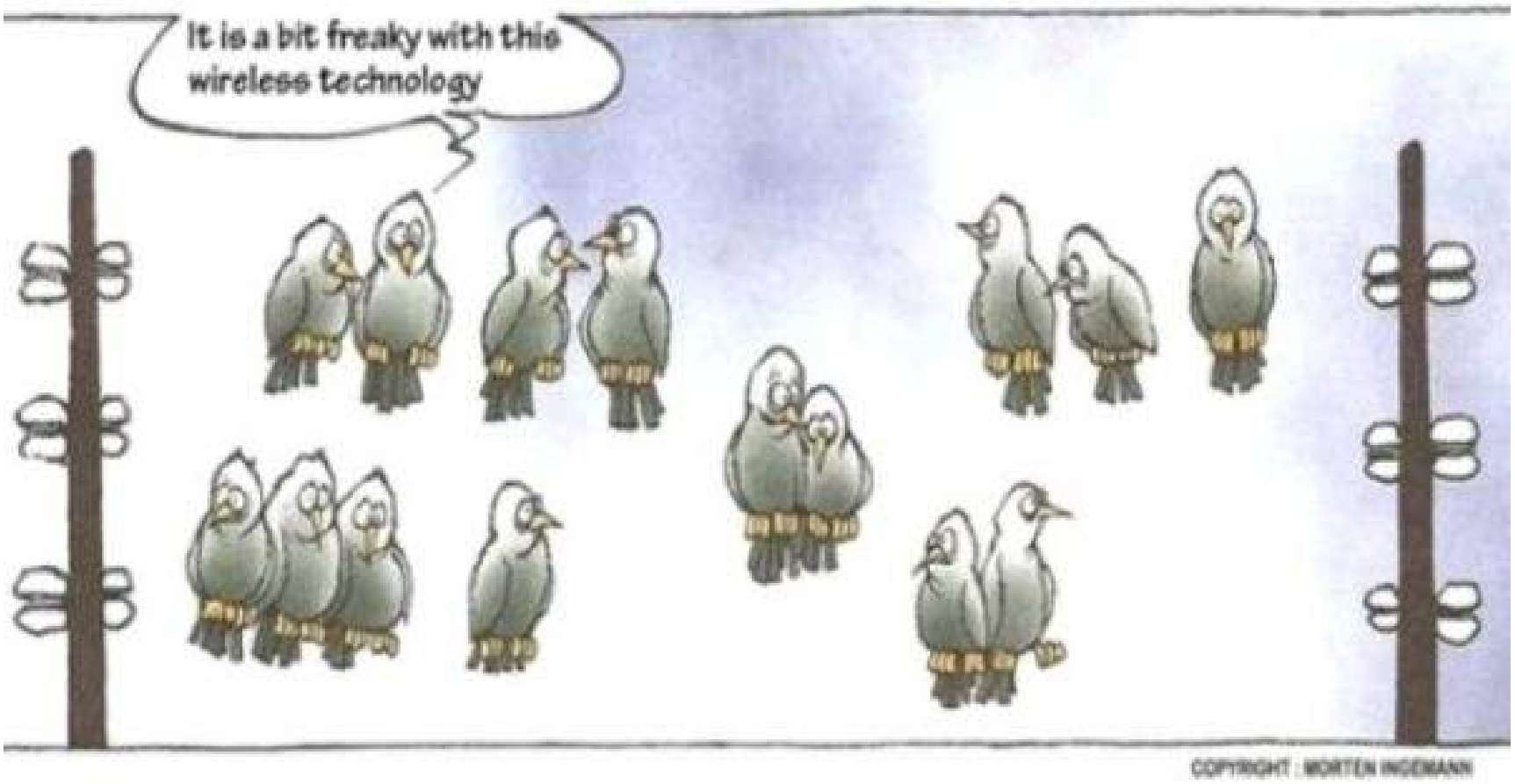
So, for new routes – fiber wins

- Costly installation
  - Require special skills
  - Can be damaged by being bent
- Interfaces are more expensive



https://www.dignited.com/58676/fiber-optic-vs-copper-cables/

Wireless (Unguided) Transmission



Wireless (Unguided) Transmission

Signal carried in Electromagnetic Spectrum

James Clerk Maxwell
1864

Heinrich Hertz
1887

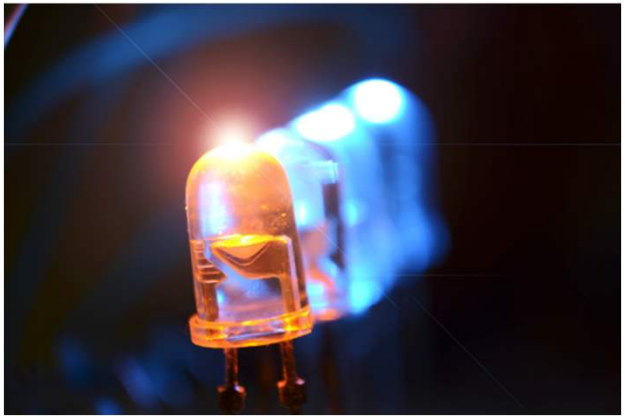
Guglielmo Marconi
1890

Examples

← Microwave Transmission

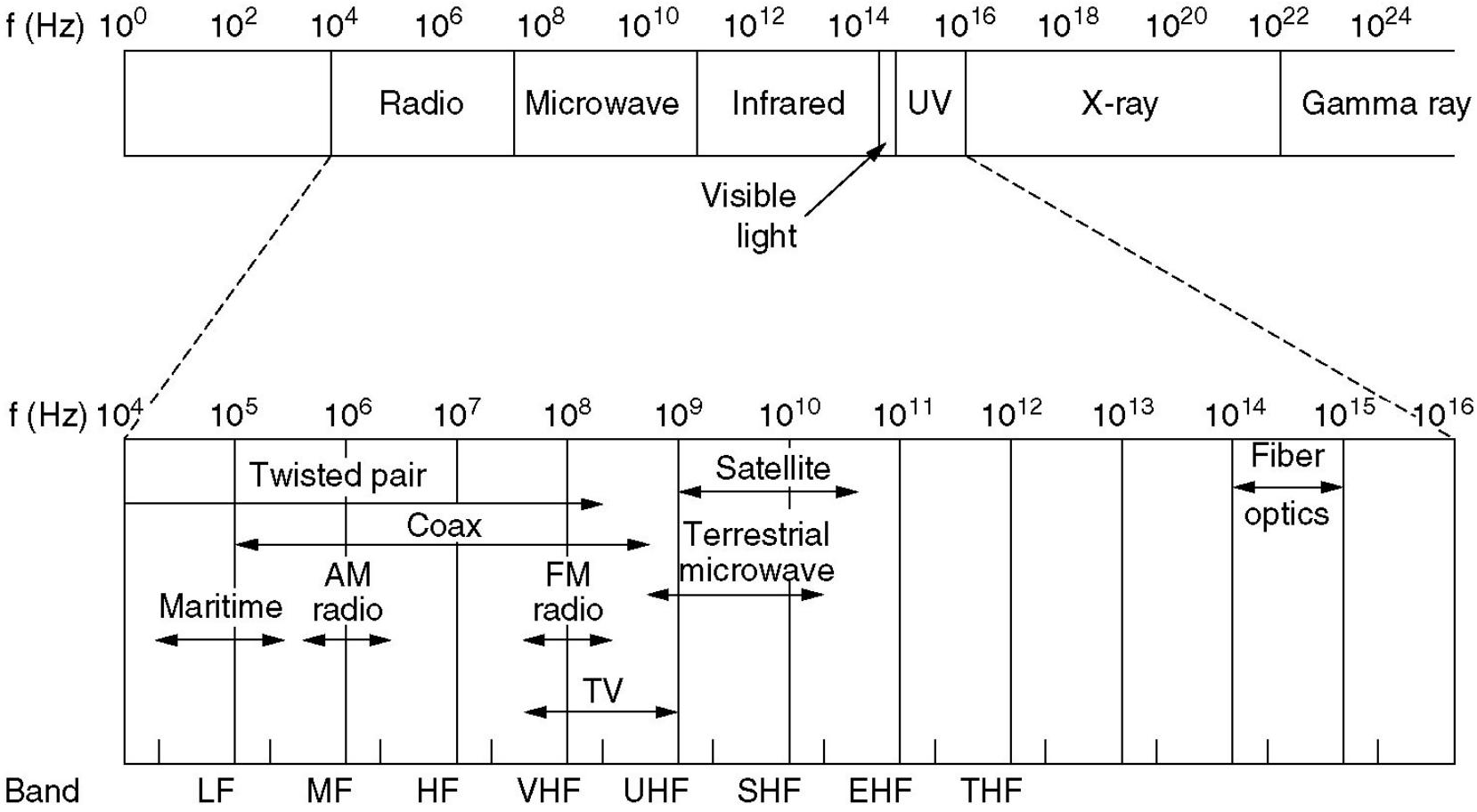
Infrared and Millimeter Waves →

- Lightwave Transmission



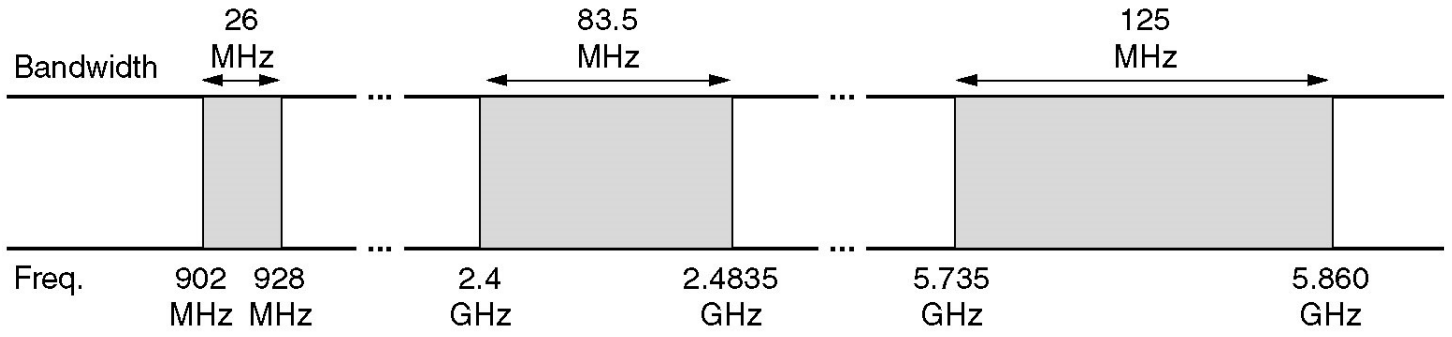
Electromagnetic Spectrum

A publicly regulated, scarce resource!



Electromagnetic Spectrum

- Regulated by Federal Communications Commission (**FCC)** in USA
- **ACMA** (Australian Communications & Media Authority) in Australia.
- Australian Radiofrequency Spectrum Plan outlines how spectrum is used in Australia.



ISM bands

902-928 Mhz
in America only.

Radio Frequency

- Travel long distance
- Easy to generate
- Can penetrate buildings easily
- Radio waves are omnidirectional

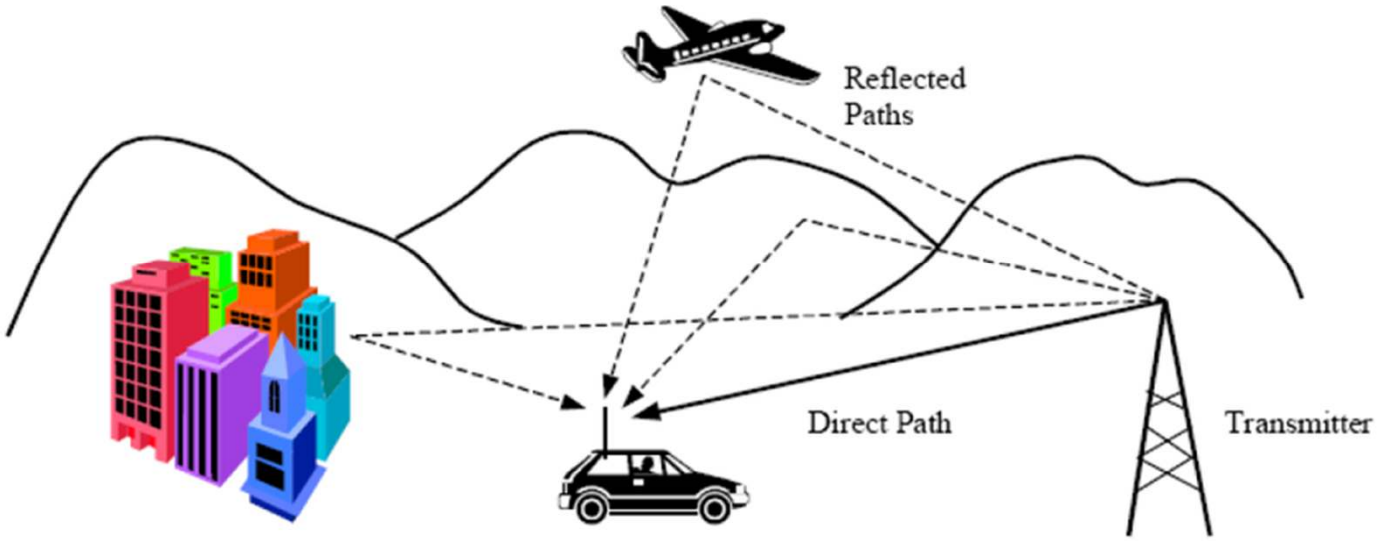
Microwave transmission

- Microwaves are directional
- Do not penetrate as well as the radio waves
- Widely used for mobile communications

Propagation environment effects

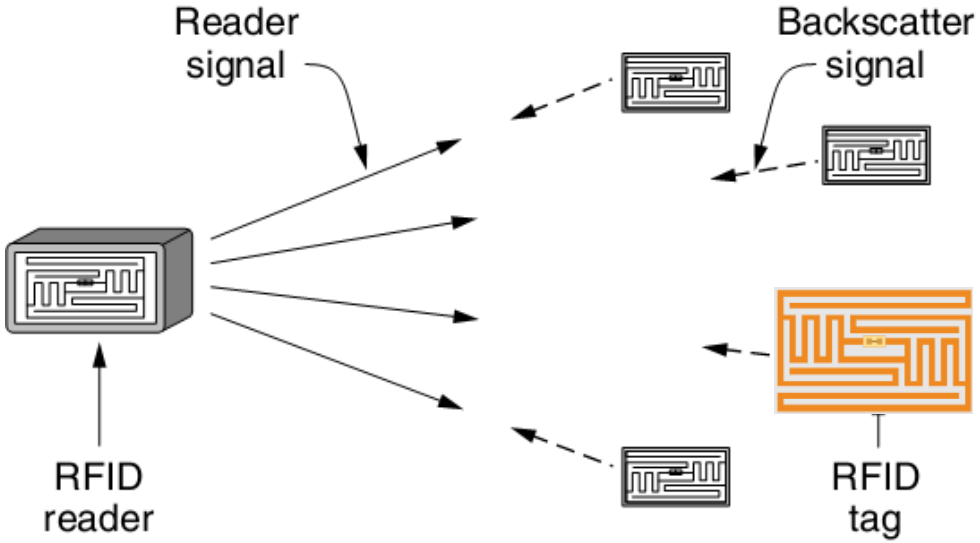
Suffers from

- Path loss
- Multipath effect
- Shadowing
- Interference



https://www.researchgate.net/figure/1-Effect-of-multipath-on-mobile-receiver-The-multipath-effect-like-Doppler-spread_fig1_44151936

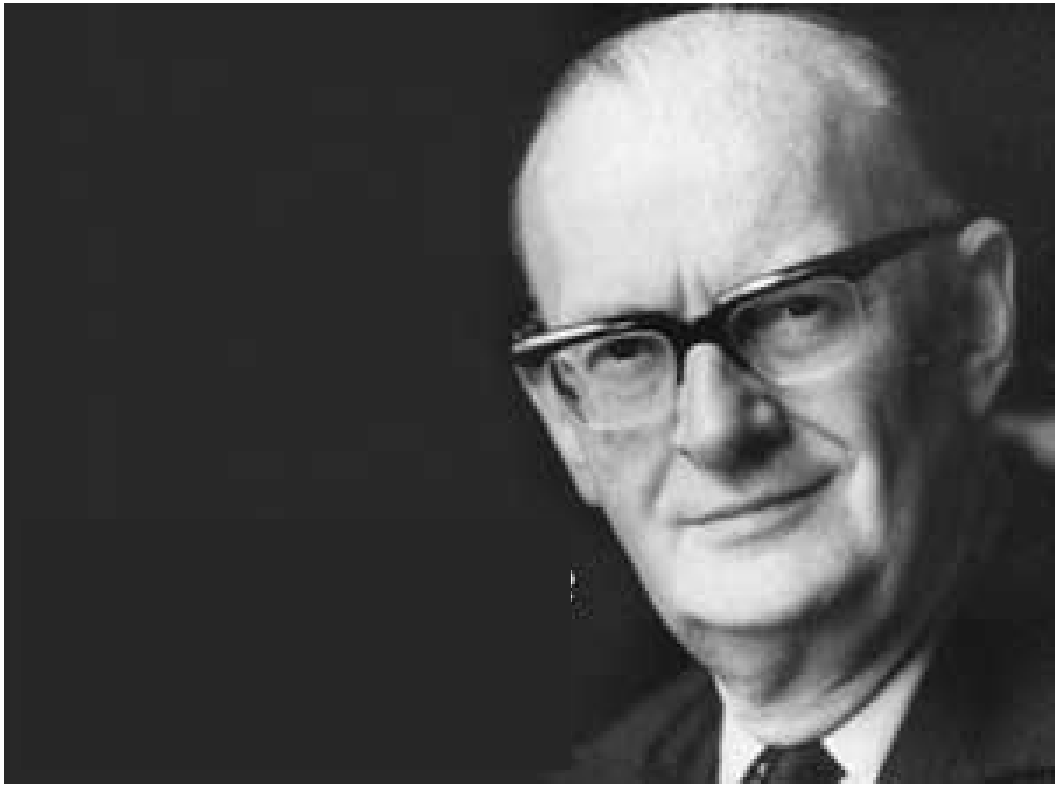
Near Field Communications: RFID and NFC



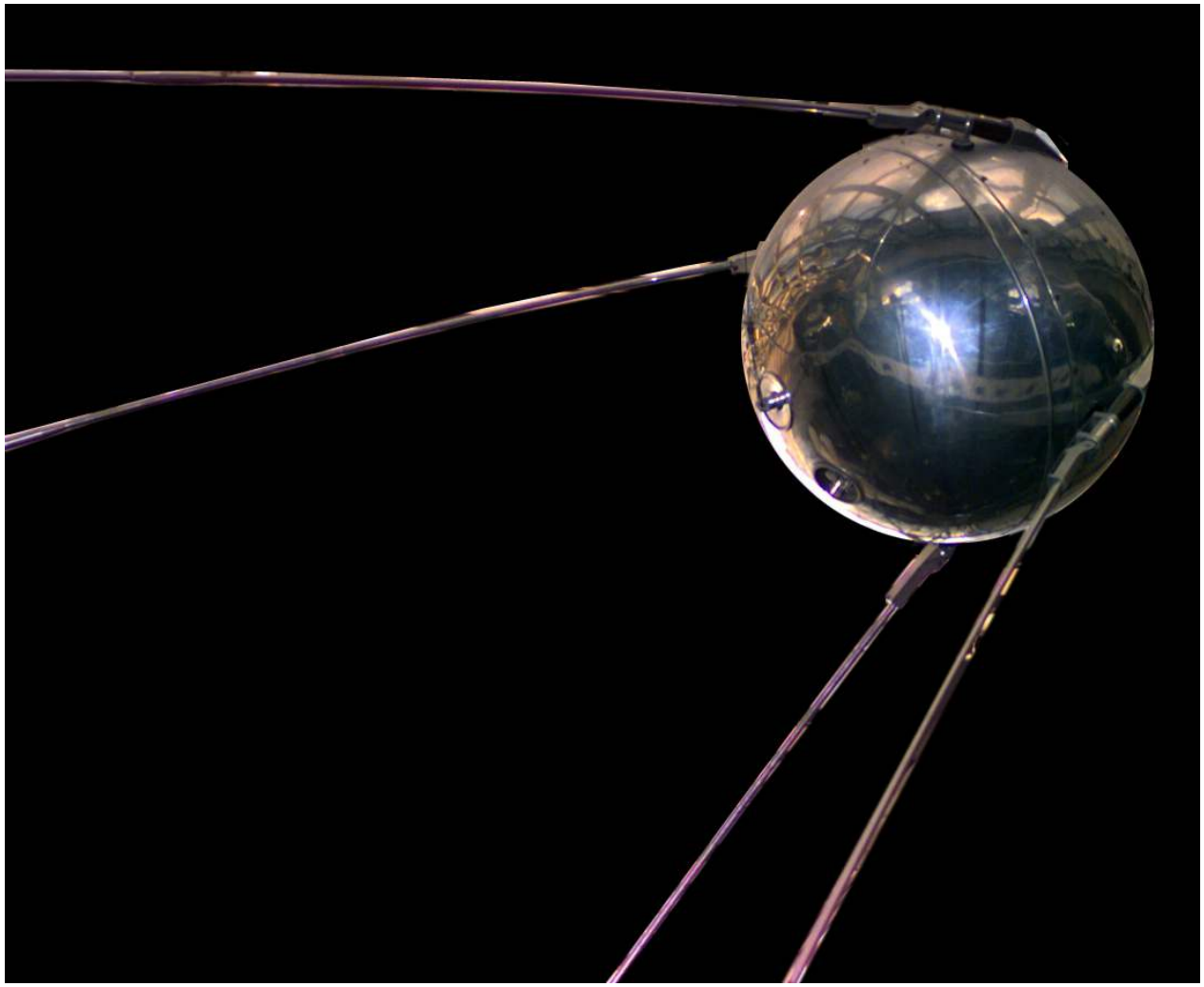
- The RFID reader always transmits a signal.
- Backscatter is a low-energy way for the tag to create a weak signal of its own that shows up at the reader.
- For the reader to decode the incoming signal, it must filter out the outgoing signal that it is transmitting.

- NFC (Near field communication) is a subset of RFID with a shorter range for security purposes.
- In 2004, Nokia, Sony, and Philips formed the NFC Forum.
- *Applications*: contactless transactions, access digital content, connect electronic devices

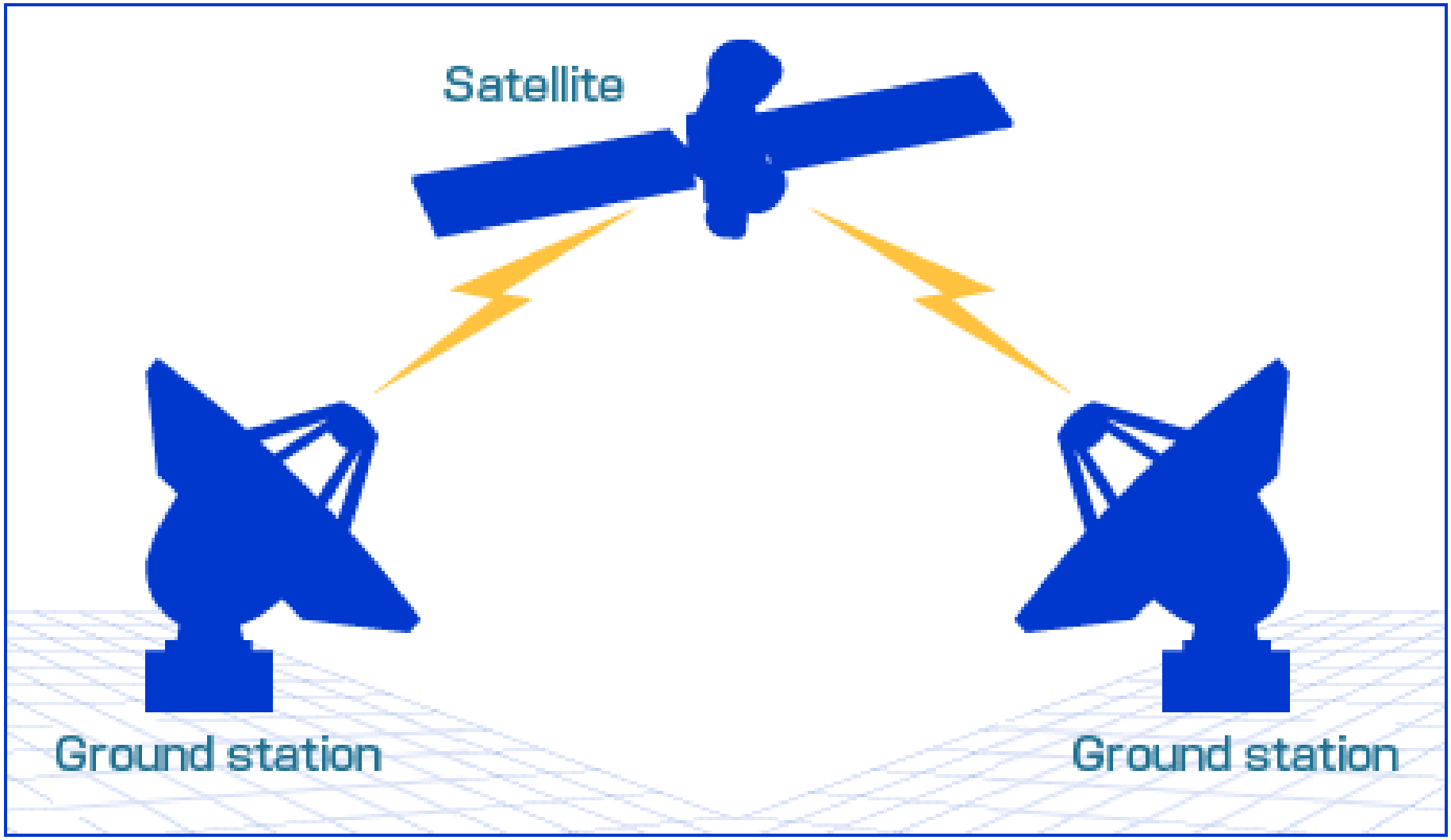
Satellite Communication



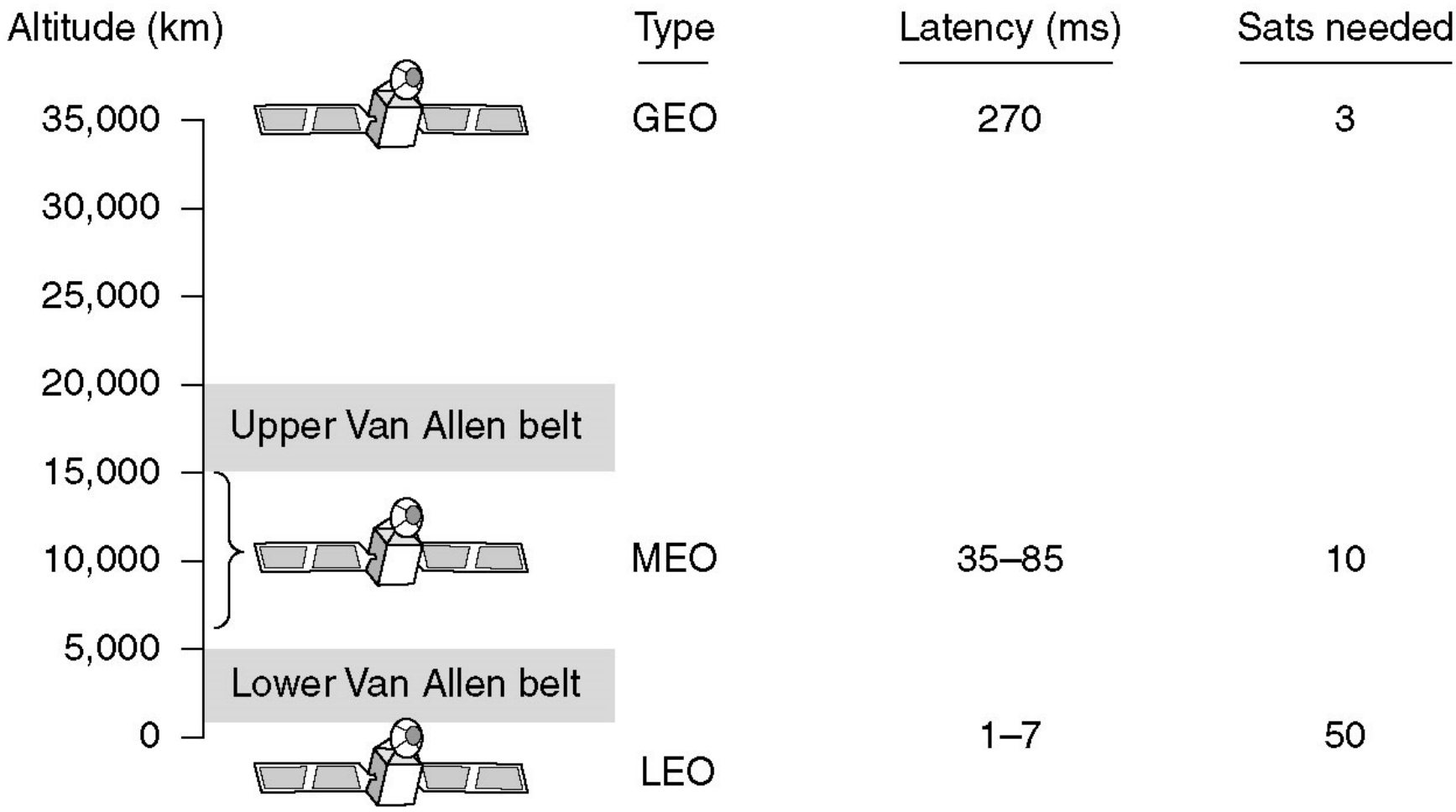
Sputnik 1



Satellite Communication



Satellite Communication



Type	Latency (ms)	Sats needed
GEO	270	3
MEO	35–85	10
LEO	1–7	50

GEO (Geostationary Earth Orbit): stationary

MEO (Medium-Earth Orbit) satellites drift slowly in longitude; appr. 6 hours to circle the earth.

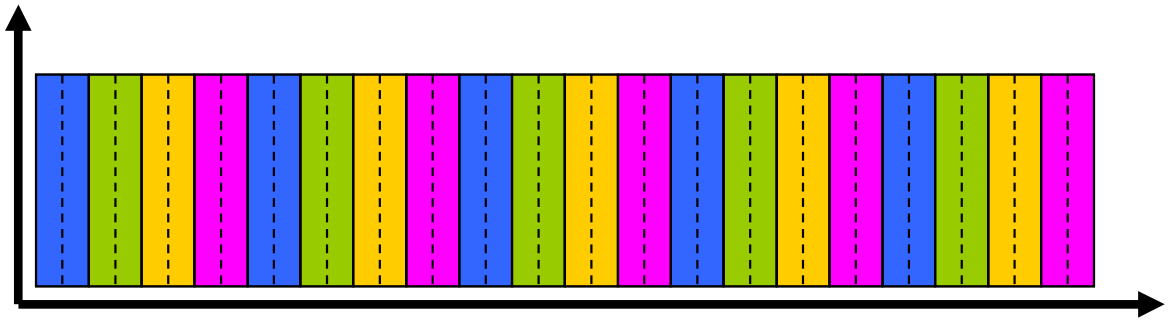
LEO (Low-Earth Orbit) satellites move rapidly.

To prevent total chaos in the sky, orbit slot allocation is done by ITU.

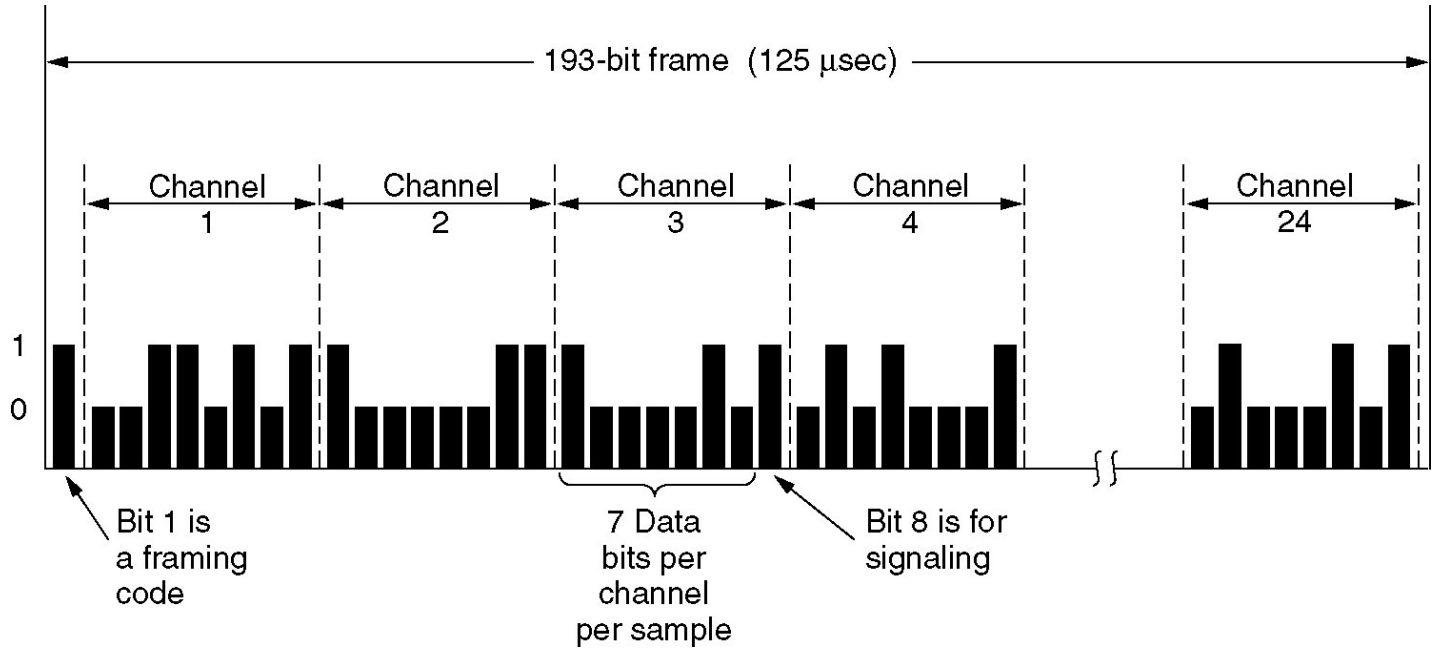
Multiplexing (sharing the medium)

- Time Division Multiplexing (TDM)
- Frequency Division Multiplexing (FDM)
- Code Division Multiplexing (CDM)
- Wavelength Division Multiplexing (WDM)

Time Division Multiplexing (TDM)



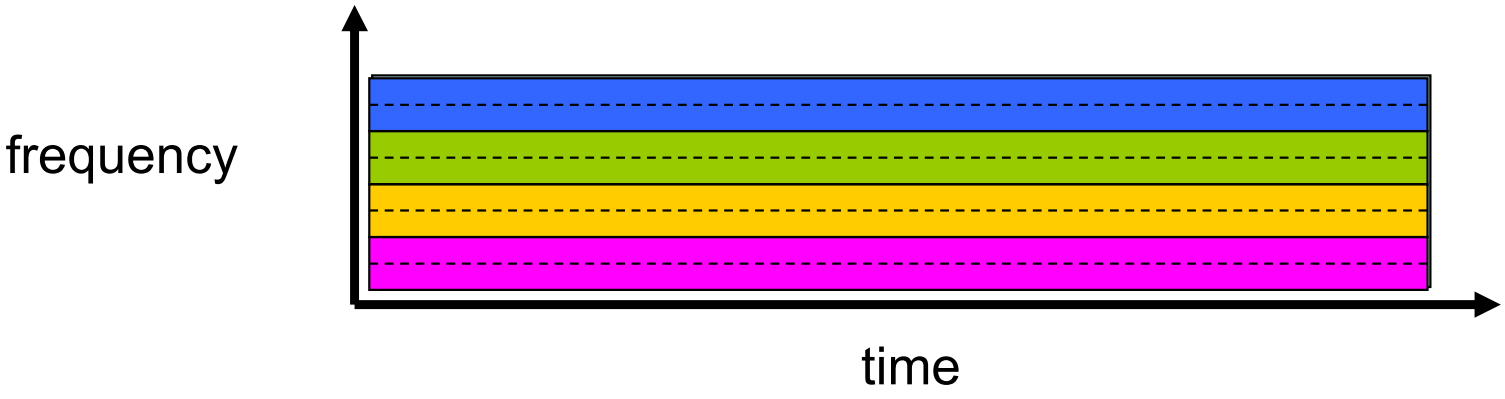
TDM with four colour-coded users



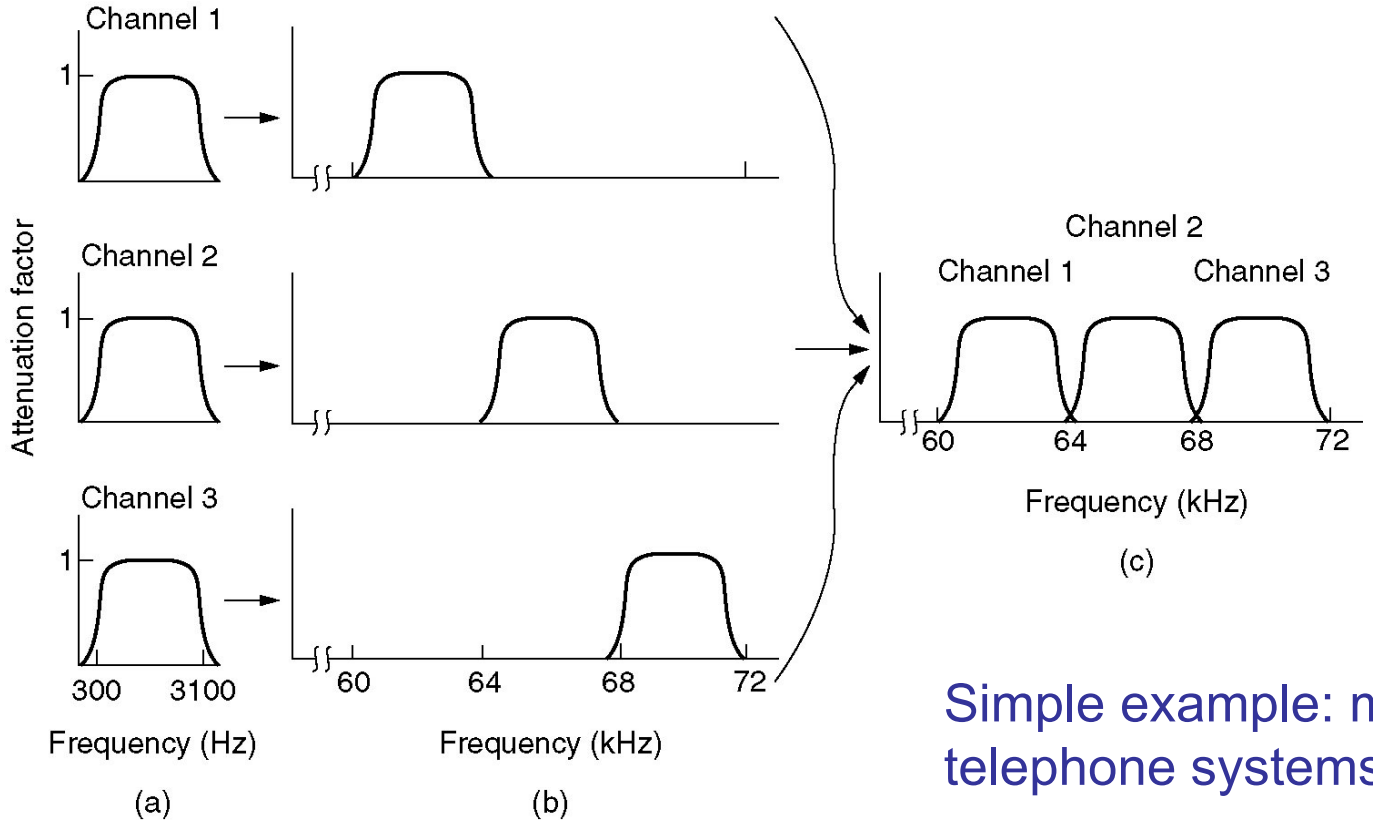
The T1 carrier (1.544 Mbps).

The T-carrier transmission system 1 (T-1), was introduced in 1960s by Bell Labs for digital transmission of multiplexed (up to 24) telephone calls simultaneously over a single transmission line of copper wire.

Frequency Division Multiplexing (FDM)

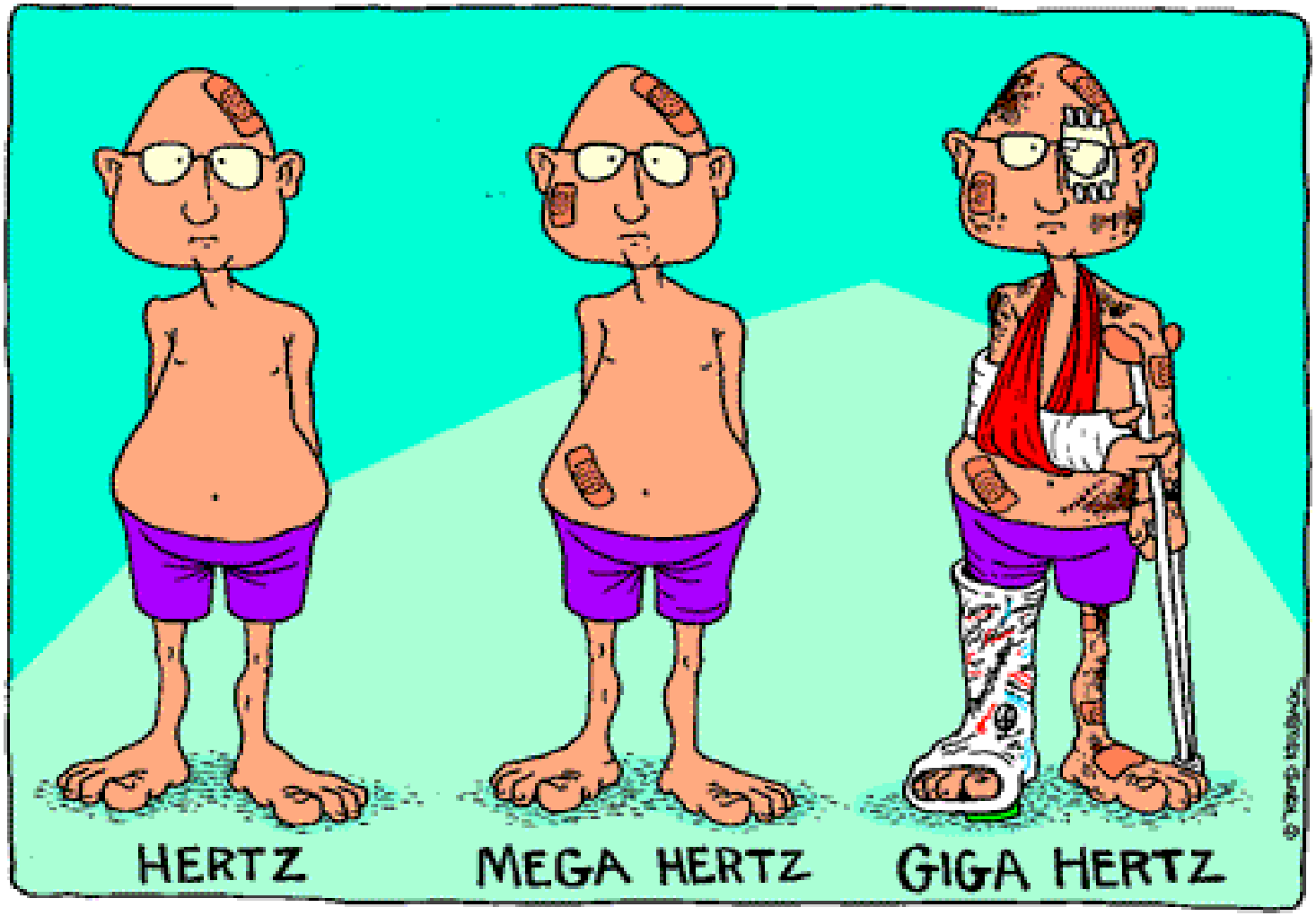


FDM with four colour-coded users

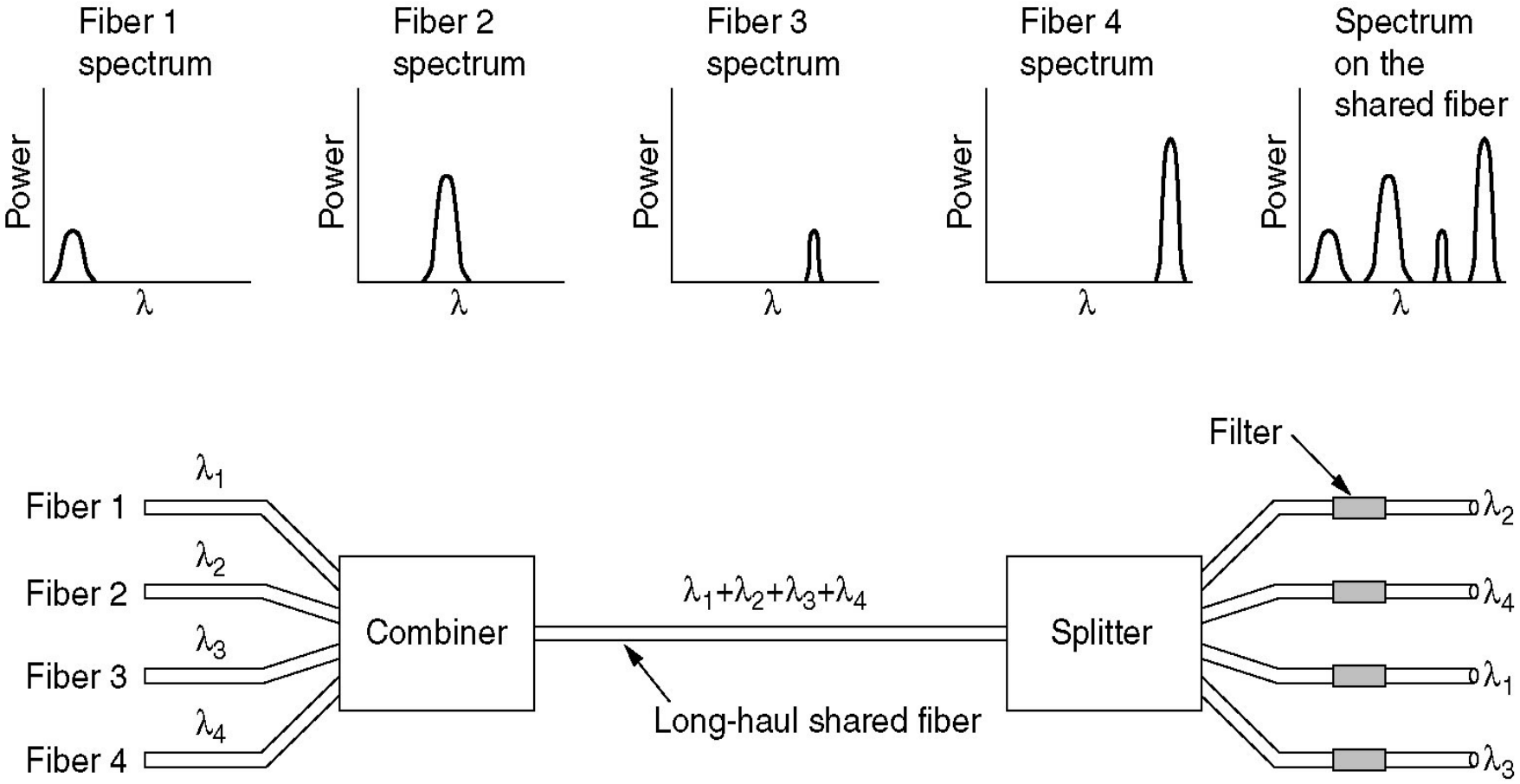


Simple example: multiplex calls in telephone systems, AM/FM Radio

My Brain Hertz…



Wavelength division multiplexing.

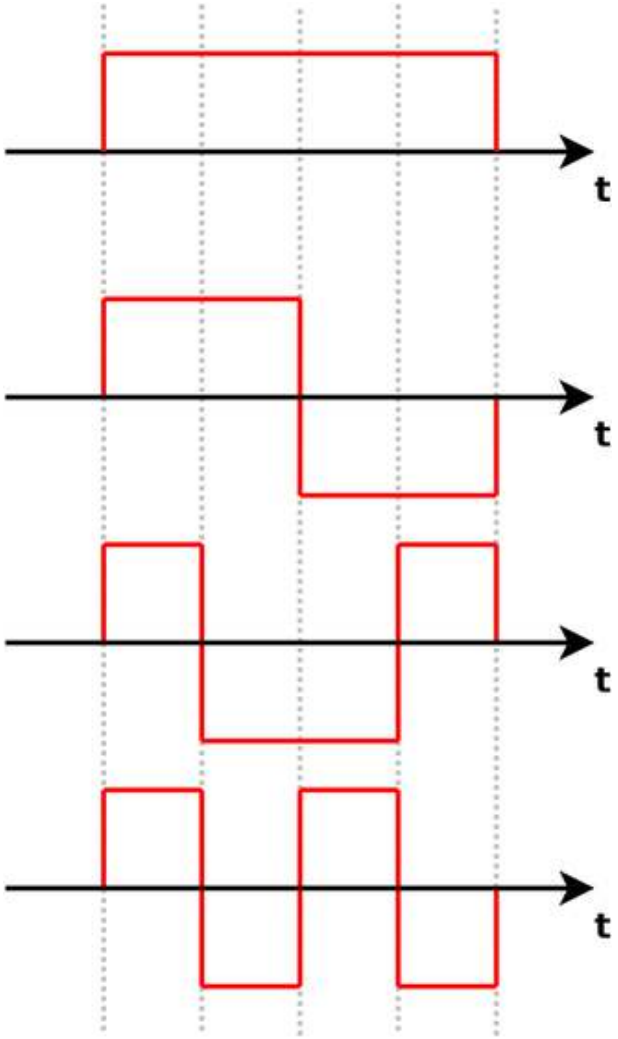


Code Division Multiple Access (CDMA)

- CDMA allows each station to use the entire allocated frequency spectrum all the time.

- Analogy: Airport lounge

Code Division Multiple Access (CDMA)



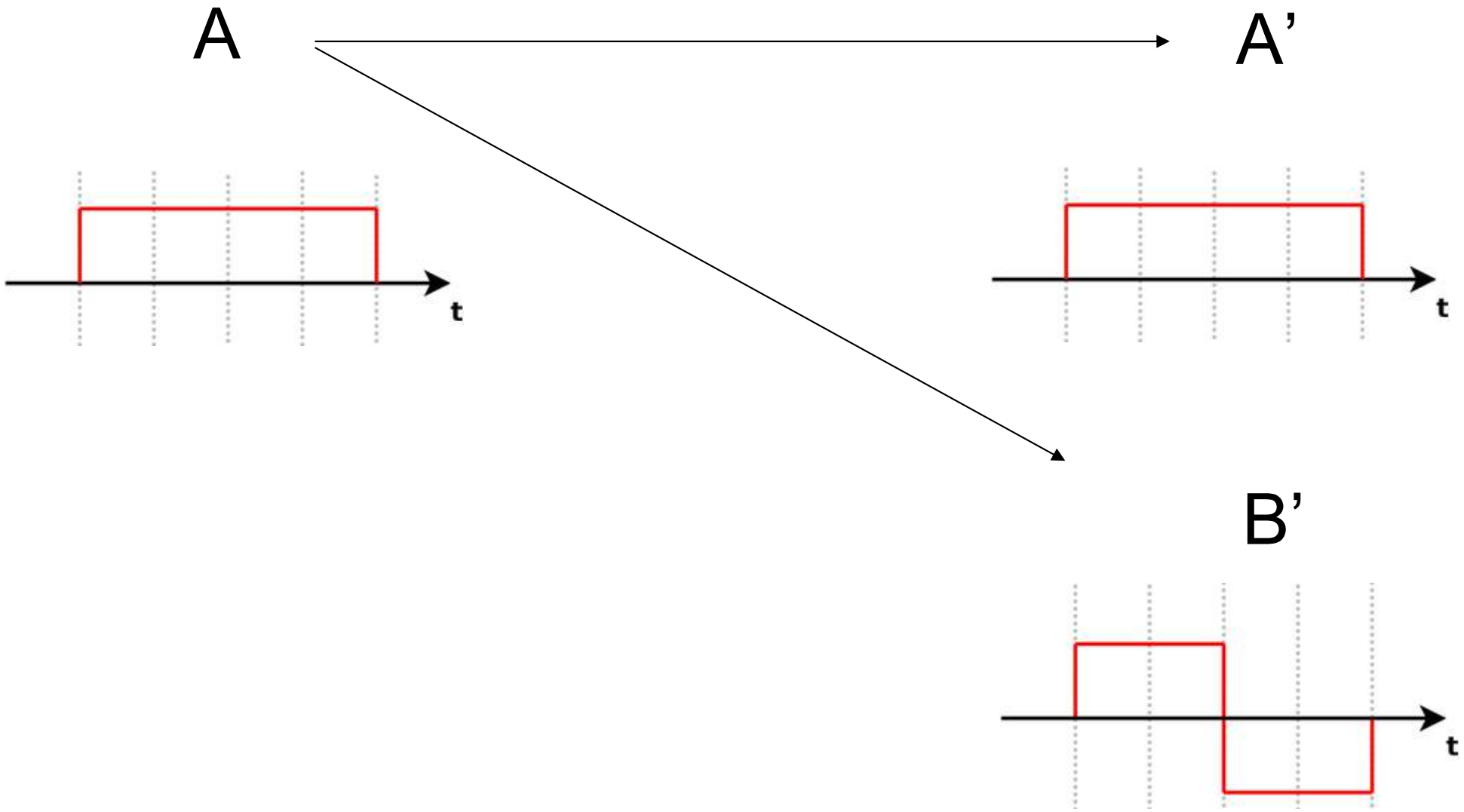
Four orthogonal signals

- Multiple simultaneous transmissions are separated using coding theory.
- Each station is assigned a unique code called a **chip sequence**, which are ***pairwise orthogonal***.
- They are generated using a method called Walsh codes.
- Let S and T be two distinct sequences

$$\mathbf{S} \bullet \mathbf{T} \equiv \frac{1}{m} \sum_{i=1}^{m} S_i T_i = 0$$

$$\mathbf{S} \bullet \mathbf{S} = \frac{1}{m} \sum_{i=1}^{m} S_i S_i = \frac{1}{m} \sum_{i=1}^{m} S_i^2 = \frac{1}{m} \sum_{i=1}^{m} (\pm 1)^2 = 1$$

Code Division Multiple Access (CDMA)



Example

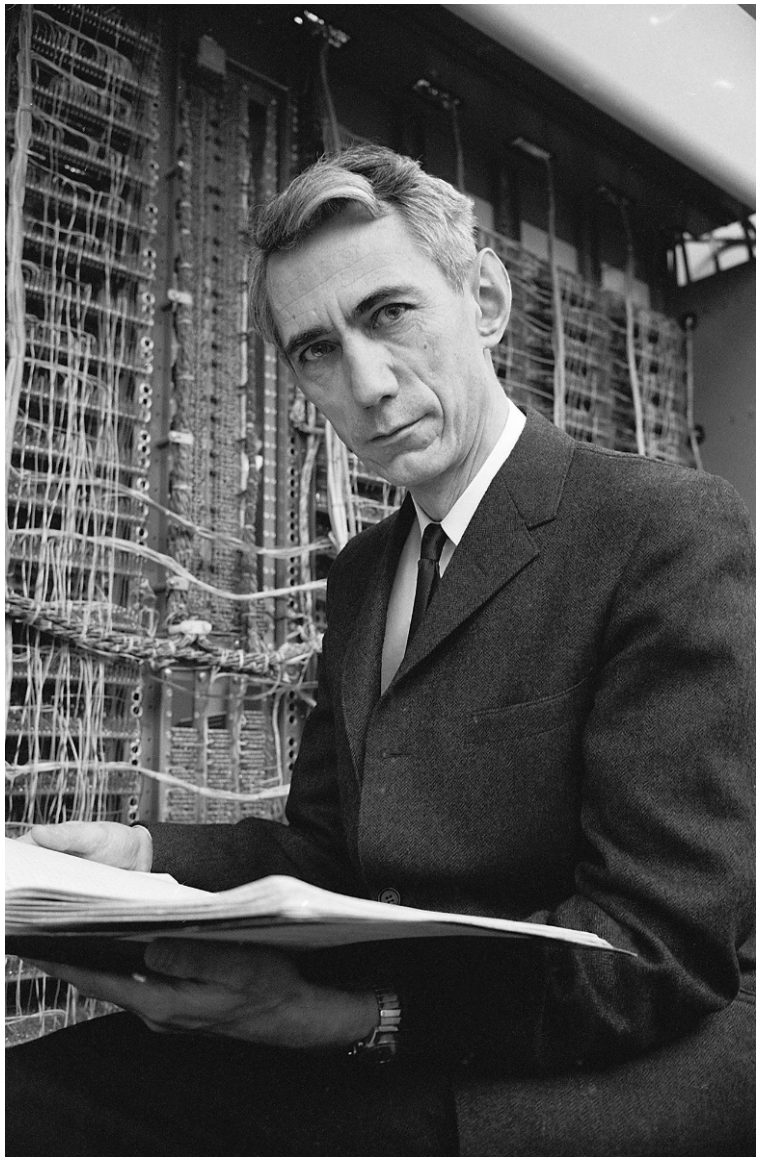
We have four stations A, B, C and D. They are assigned the following sequences.

A = (-1 -1 -1 +1 +1 -1 +1 +1)
B = (-1 -1 +1 -1 +1 +1 +1 -1)
C = (-1 +1 -1 +1 +1 +1 -1 -1)
D = (-1 +1 -1 -1 -1 -1 +1 -1)

What is the recovery of station C's signal when

a) C transmits 1 bit
b) Both B and C transmits 1 bit
c) A and B transmit bits
d) A transmits 1 bit C transmits -1

Fundamental Limits



Claude Shannon

- The father of the information theory
- **Information theory** studies the quantification of information
- **Coding theory** is one of the most important and direct applications of information theory.
  - Source coding (e.g. for data compression)
  - Channel coding (e.g. error-correcting codes)

Fundamental Limits

- **Channel capacity** is the upper bound on the rate of information that can be reliably transmitted over a communications channel.

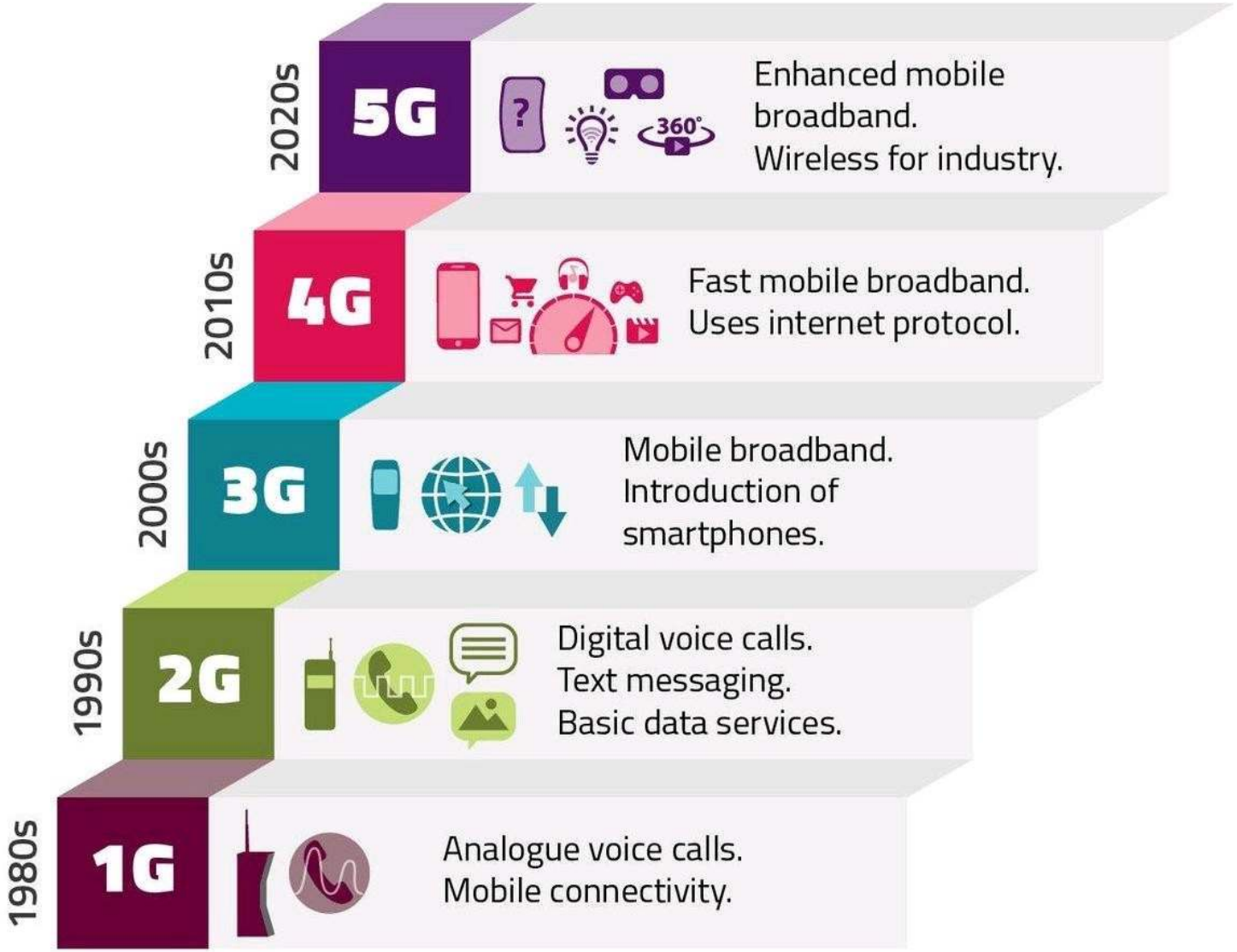
- Capacity of a noisy channel of which the bandwidth is B Hz and the signal-to-noise ratio is S/N is given be

Maximum data rate = B $\log_2(1 + S/N)$ bits/sec

Example

What is the capacity of a noisy communication channel that has a bandwidth of 1MHz and a signal to noise ratio of 40 dB

Cellular Networks



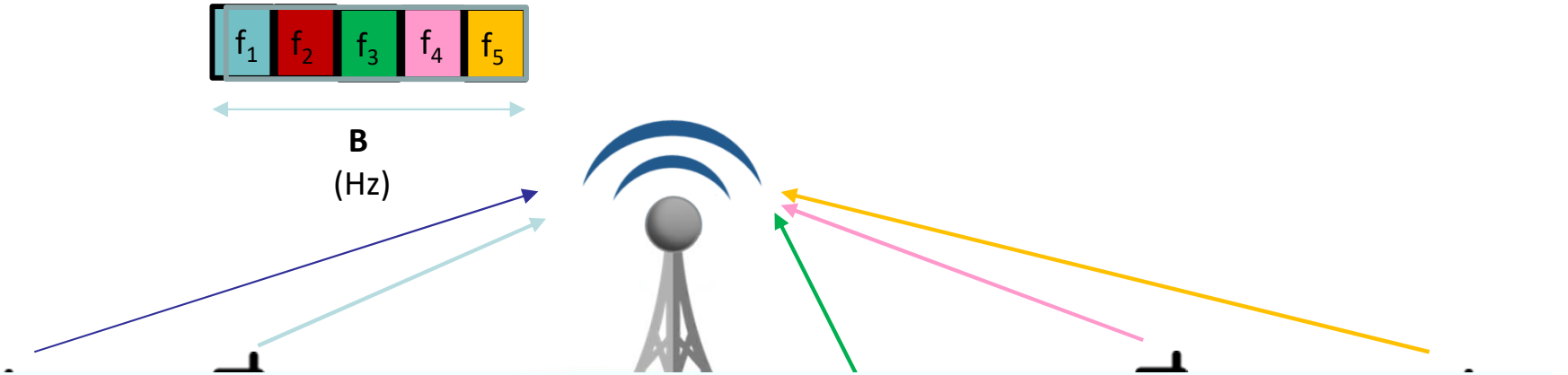
https://twitter.com/5GBarcelona/status/1189150444398043136

What is next?

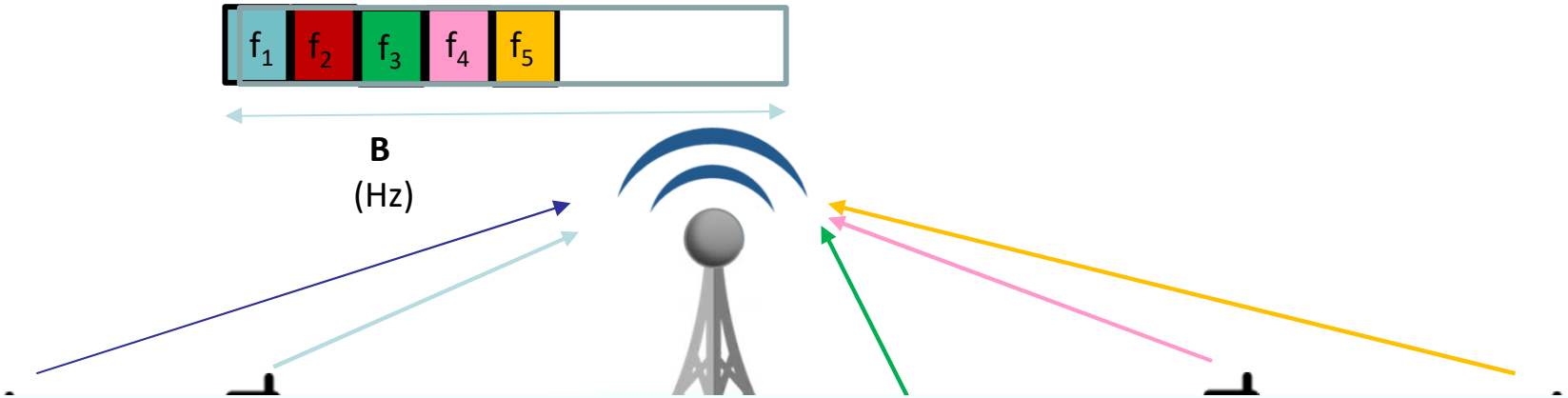
Cellular Network

B
(Hz)

Cellular Network

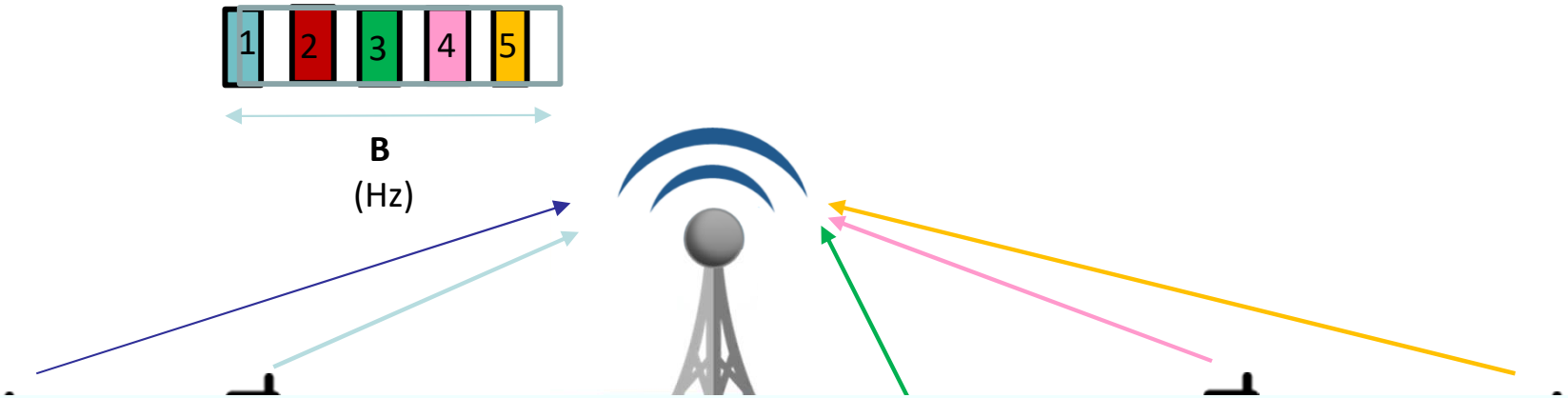


Cellular Network



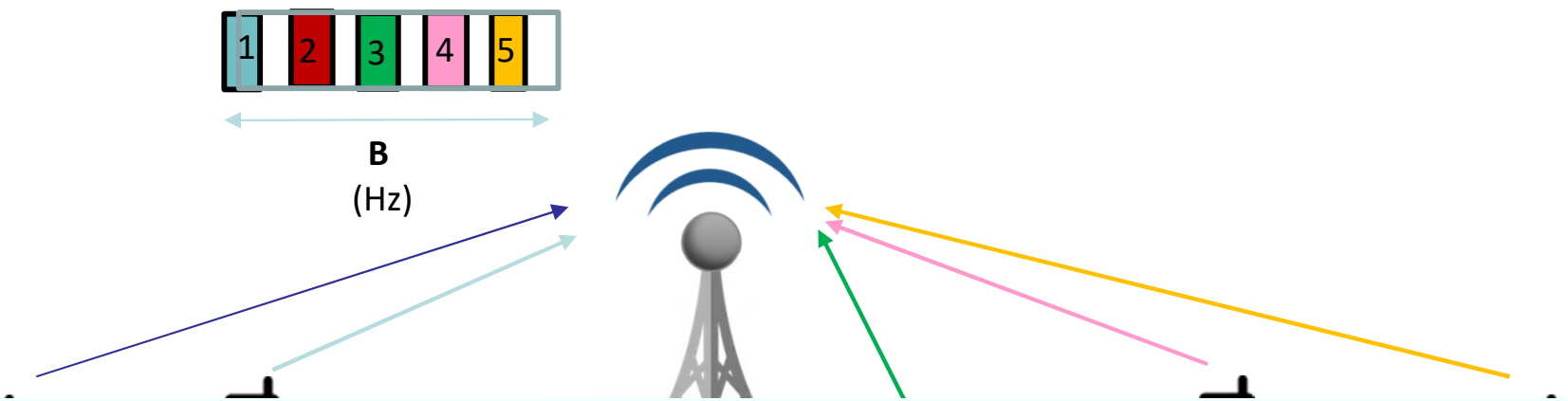
Increase the available spectrum

Cellular Network



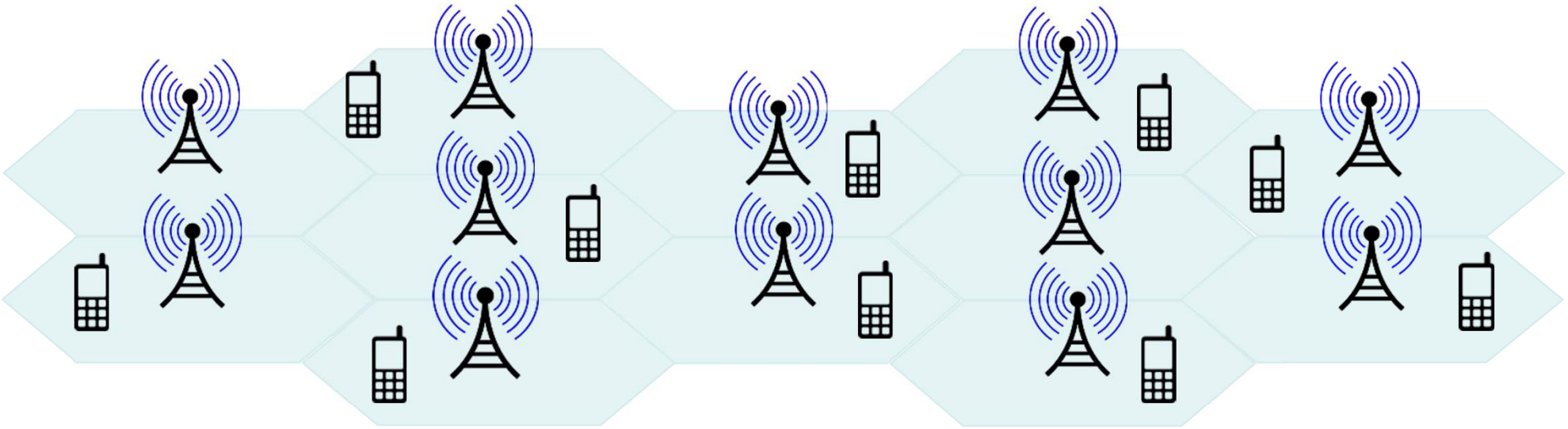
Improve the spectral efficiency

Cellular Network



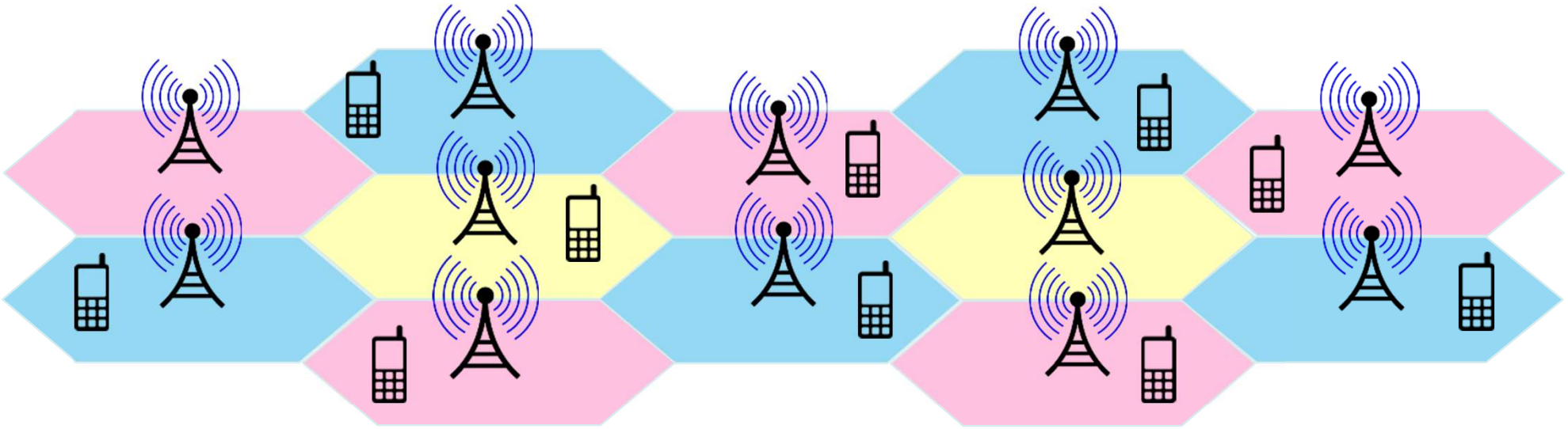
Improve the spectral efficiency

Cellular Network



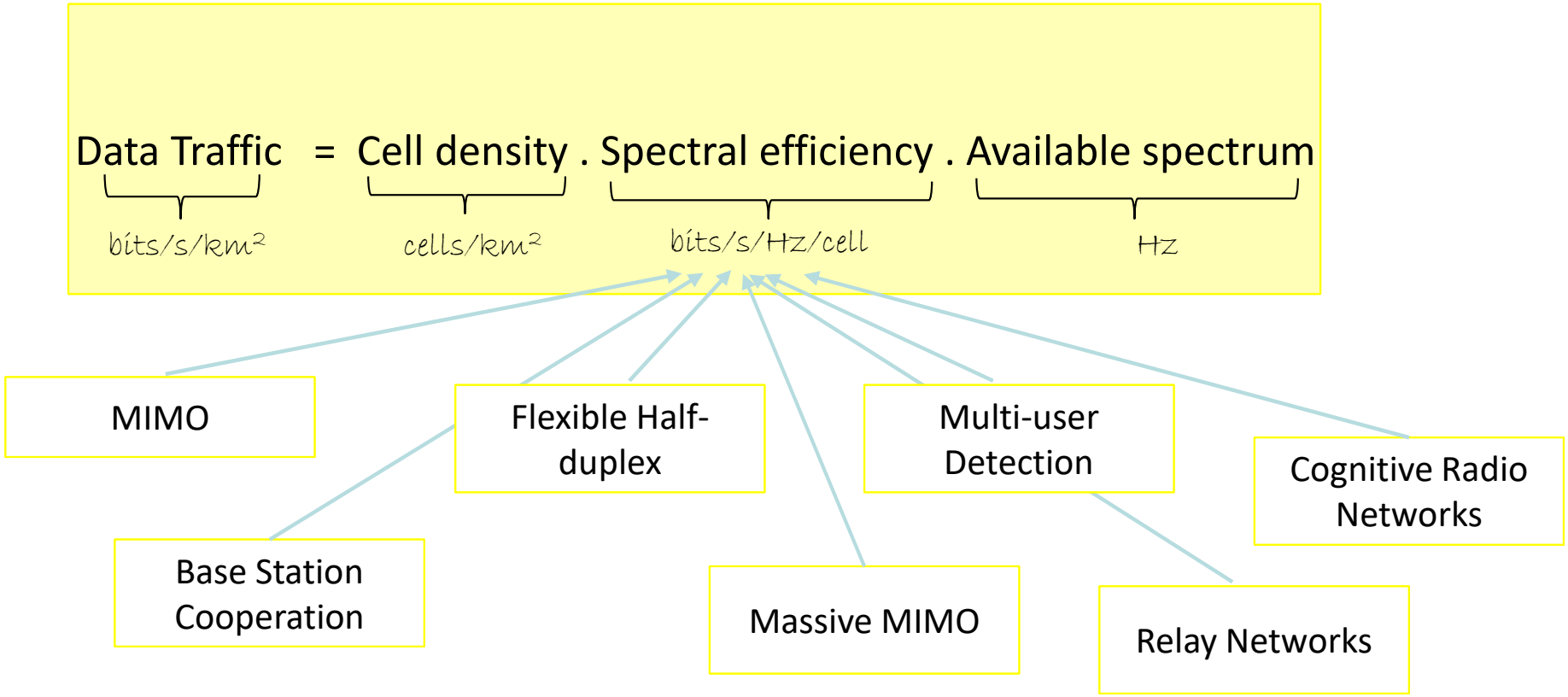
Deploy more cells

Cellular Network



Deploy more cells

Our research



Learning Objectives

You should now know about

- Transmission media
  - Guided
    - Copper
    - Fiber optics
  - Unguided
    - Wireless Communications
    - Environmental effects
- Multiplexing
- Fundamental limits
- Example: Cellular Network