Mobile Wireless Communications 101

CSCI3310 Mobile Computing & Application Development

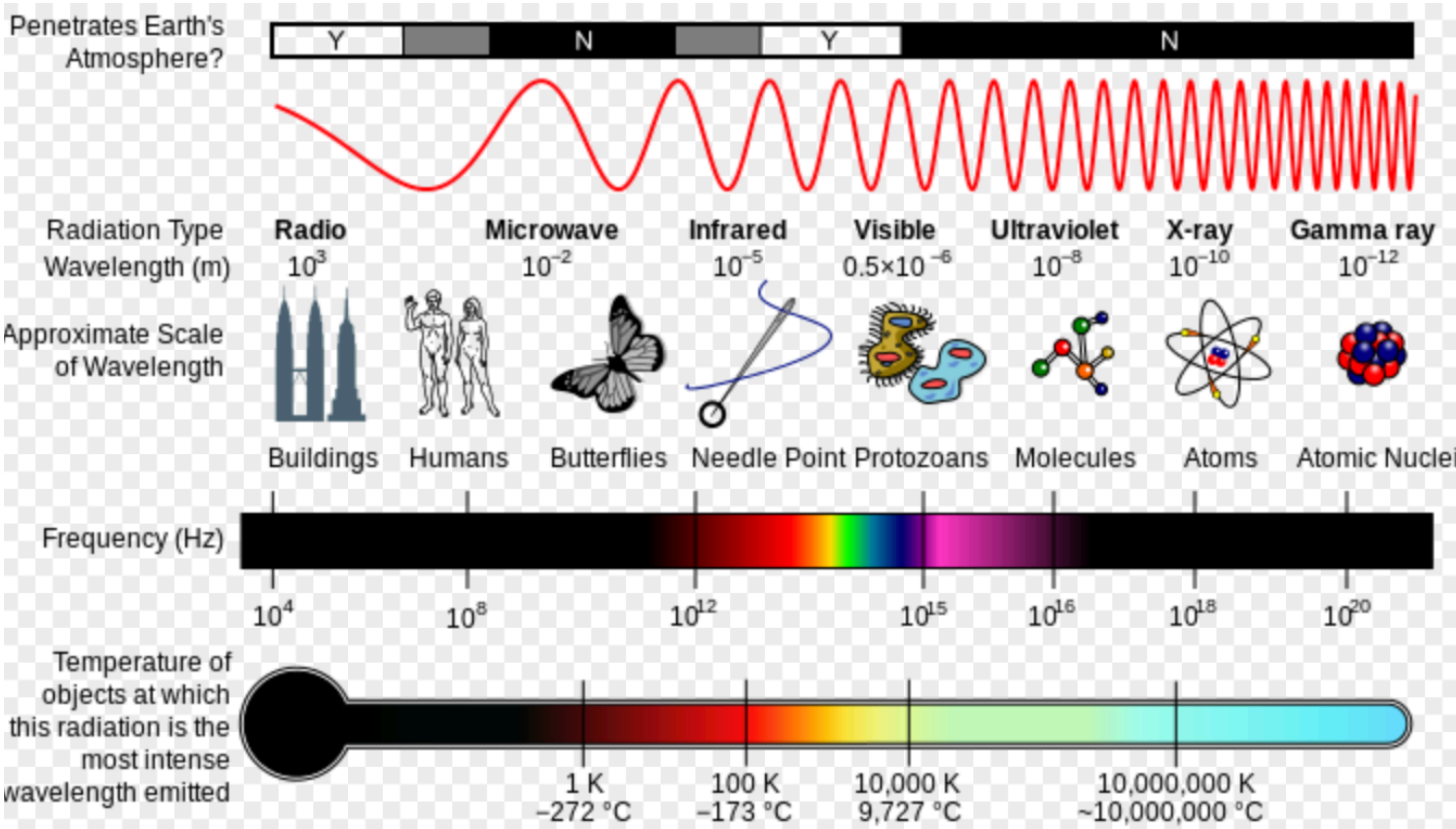
Question

- Why **Carrier Signal** is needed?
- Which **frequencies** are for our mobile?
- What affects the **propagation** of signal?
- (Optional) How **multiple access** in the “same air” is handled?

Wireless Communications

- Communications at any Time and Anywhere
- Brief history
  - Ancient Systems: Carrier Pigeons, Smoke Signals
  - Radio invented in the 1880s by Marconi
  - Many sophisticated military radio systems were developed during and after WW2

Electromagnetic Spectrum



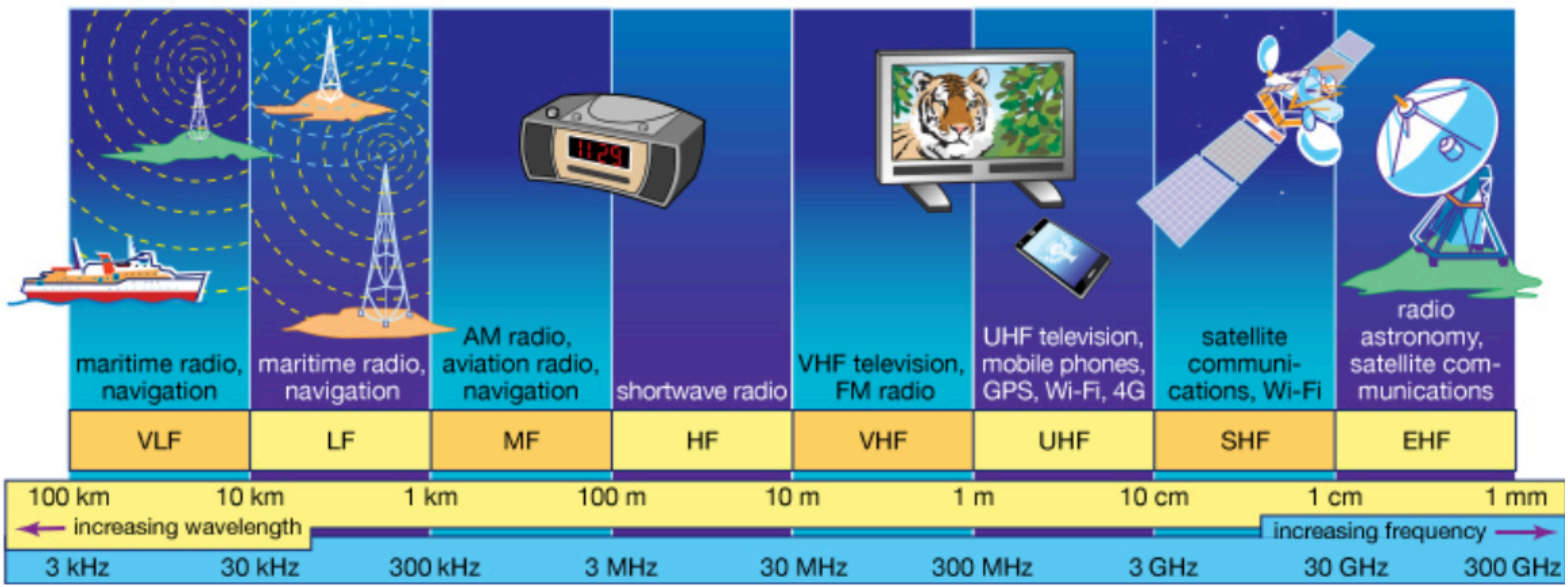
Frequency and wave length:

$$\lambda = c/f$$

wave length λ, speed of light $c \cong 3\text{x}10^8$m/s, frequency f

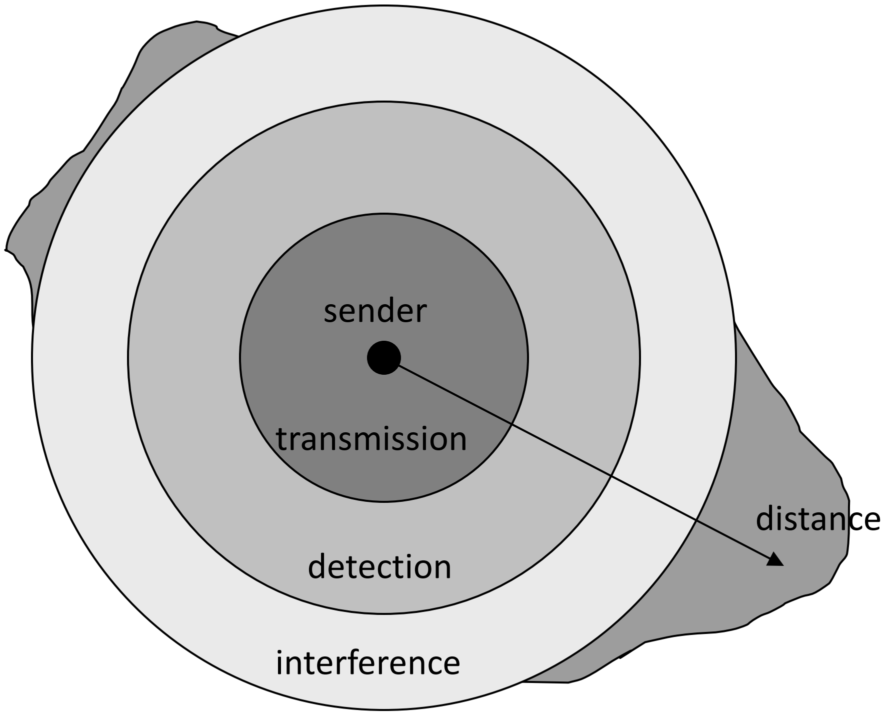
Radio Waves

- The radio spectrum is the part of the electromagnetic spectrum from <u>3Hz</u> to <u>3THz</u>
- **Band** ： a small section of the radio communication frequencies



Signal propagation ranges

- **Transmission range**
  - communication possible
  - low error rate
- **Detection range**
  - detection of the signal possible
  - no communication possible
- **Interference range**
  - signal may not be detected
  - signal adds to the background noise

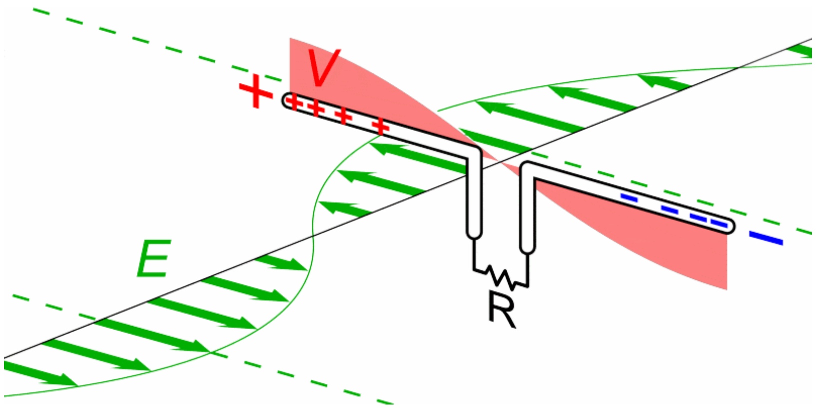


Signal propagation

- Propagation in free space always like light (straight line)
- **Receiving power proportional to $1/d^2$** in vacuum – much more in real environments
  (d = distance between sender and receiver)
- **Path loss (attenuation)**
- Fundamental propagation behaviors:
  - **ground wave (<2MHz):** follow earth's surface, long distances (submarine communication, AM radio)
  - **sky wave (2-30MHz):** reflected at ionosphere, around the world (intl. broadcasts, amateur radio)
  - **line-of-sight (>30MHz)**: LOS, straight line, waves are bent by atmosphere due to refraction (mobile phones, satellite, cordless)
- Most systems we will discuss work with >100MHz: LOS (<u>question: why and how do mobile phones work then???</u>)

Antenna Size

- An **antenna** – usually 1/2 wavelength long – split at the exact center for connection to a feed line.
  - Dipoles are the most common wire **antenna**. **Length** is equal to 1/2 of the wavelength (λ) for the frequency of operation.
  - **Monopole** - one half of a dipole **antenna** (i.e. = $\lambda/4$), almost always mounted above some sort of ground plane.



Frequencies for Mobile Communication

- Low Frequencies:
  - low data rates
  - travel long distances
  - follow Earth's surface
  - penetrate objects and water (submarine communication)
- High Frequencies:
  - high data rates
  - short distances
  - straight lines
  - cannot penetrate objects ("**Line of Sight**")?

Frequencies and Regulations

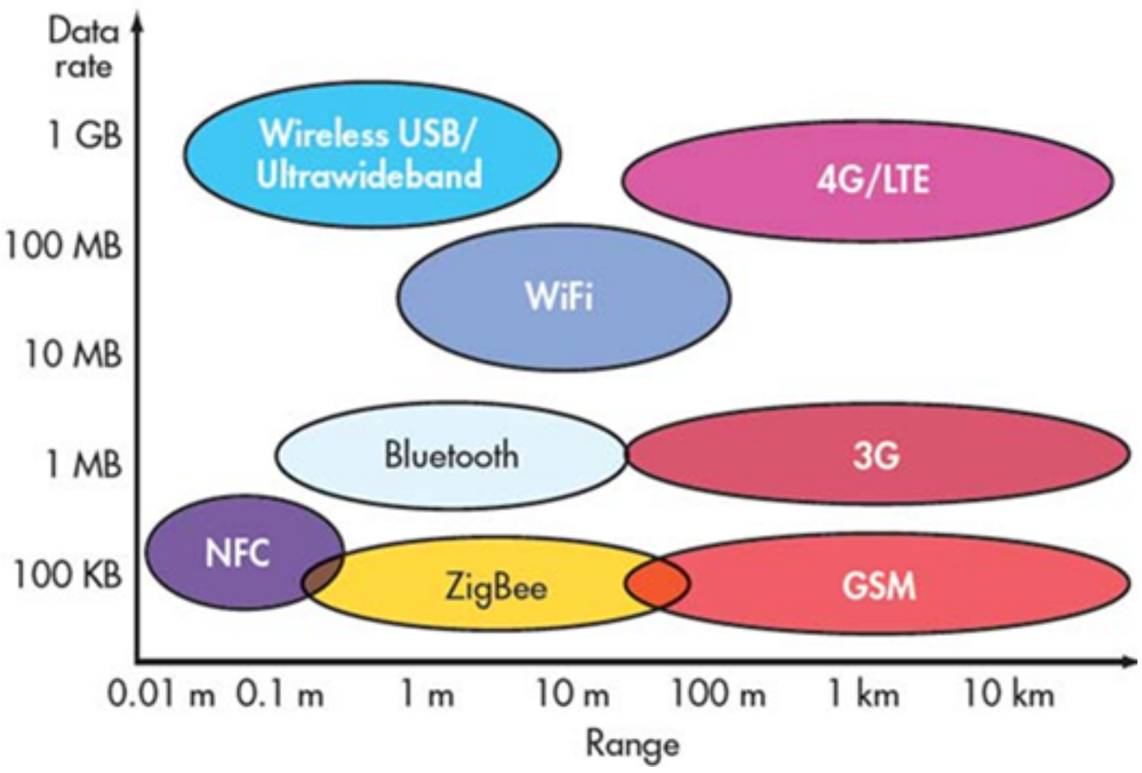
- ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

Examples	Europe	USA	Japan
Cellular phones	**GSM** 880-915, 925-960, 1710-1785, 1805-1880 **UMTS** 1920-1980, 2110-2170	**AMPS, TDMA, CDMA, GSM** 824-849, 869-894 **TDMA, CDMA, GSM, UMTS** 1850-1910, 1930-1990	**PDC, FOMA** 810-888, 893-958 **PDC** 1429-1453, 1477-1501 **FOMA** 1920-1980, 2110-2170
Cordless phones	**CT1+** 885-887, 930-932 **CT2** 864-868 **DECT** 1880-1900	**PACS** 1850-1910, 1930-1990 **PACS-UB** 1910-1930	**PHS** 1895-1918 **JCT** 245-380
Wireless LANs	**802.11b/g** 2412-2472	**802.11b/g** 2412-2462	**802.11b** 2412-2484 **802.11g** 2412-2472
Other RF systems	27, 128, 418, 433, 868	315, 915	426, 868

ITU Radiocommunication Sector (**ITU-R**) https://www.itu.int/ITU-R/

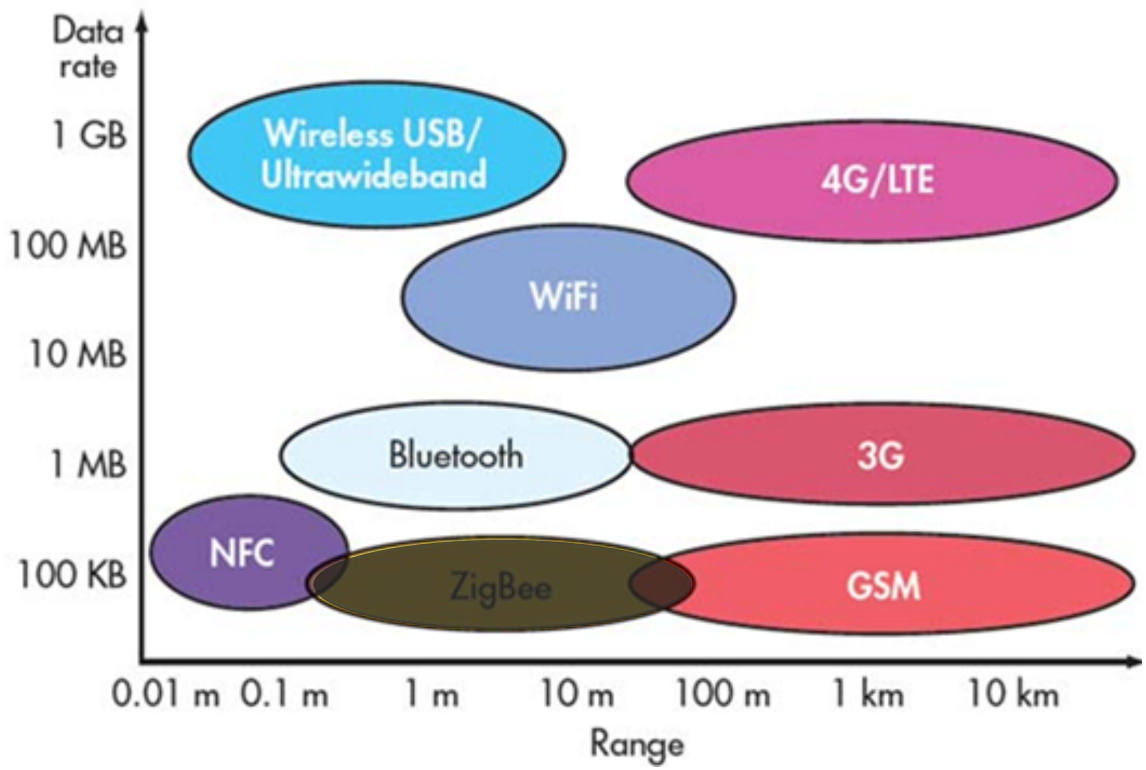
Current Wireless for Mobile

- Satellite Systems
- Cellular systems
- Wireless LANs
- Bluetooth
- Zigbee
- NFC
- NB-IoT
- …



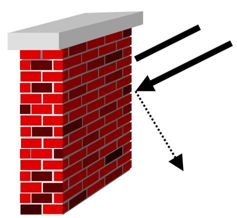
Wireless in Android

- GPS/GNSS
- GSM/3G/4G
- WiFi
- Bluetooth
- NFC

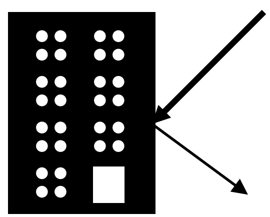


Other propagation effects

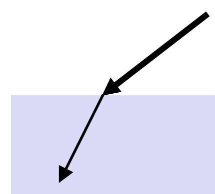
- Receiving power additionally influenced by
  - **shadowing**
  - **reflection** at large obstacles
  - **refraction** depending on the density of a medium
  - **scattering** at small obstacles
  - **diffraction** at edges



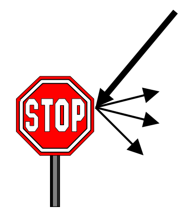
shadowing



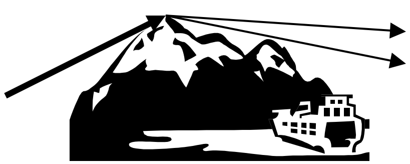
reflection



refraction



scattering



diffraction

Propagation across Obstacles

The general rule of thumb to keep in mind:

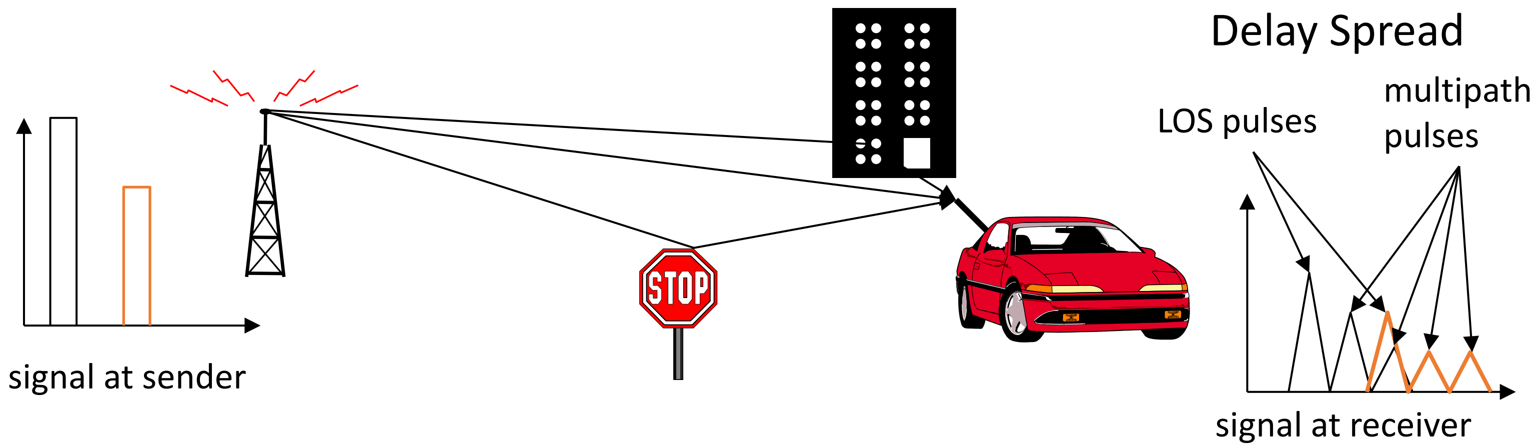
- Attenuation on obstacles
  - greater than signal wavelength (>3λ)

- Scattering on obstacles
  - Comparable but smaller than wavelength (< λ)

- Reflection on surface
  - Much greater than signal wavelength (>>λ, e.g. >30λ)

Multipath propagation

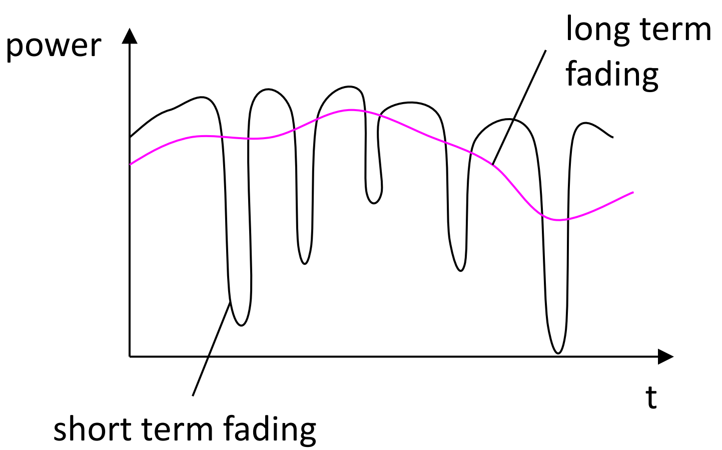
- Signal can take **many different paths** between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
  - interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

Effects of Mobility

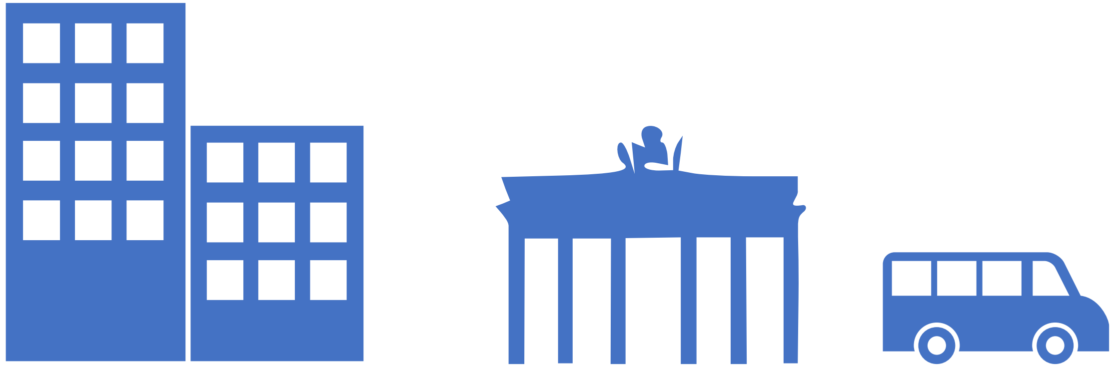
- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - ➔ quick changes in the power received (**short term fading**)

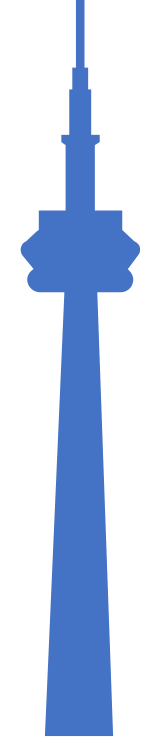


- Additional changes in
  - distance to sender
  - obstacles further away
  - ➔ slow changes in the average power received (**long term fading**)

Exercise

Given the operating frequency of GPS is 1.2GHz. What types of real world objects tends be significantly introduce the multi-path degradation for positioning system? and why?





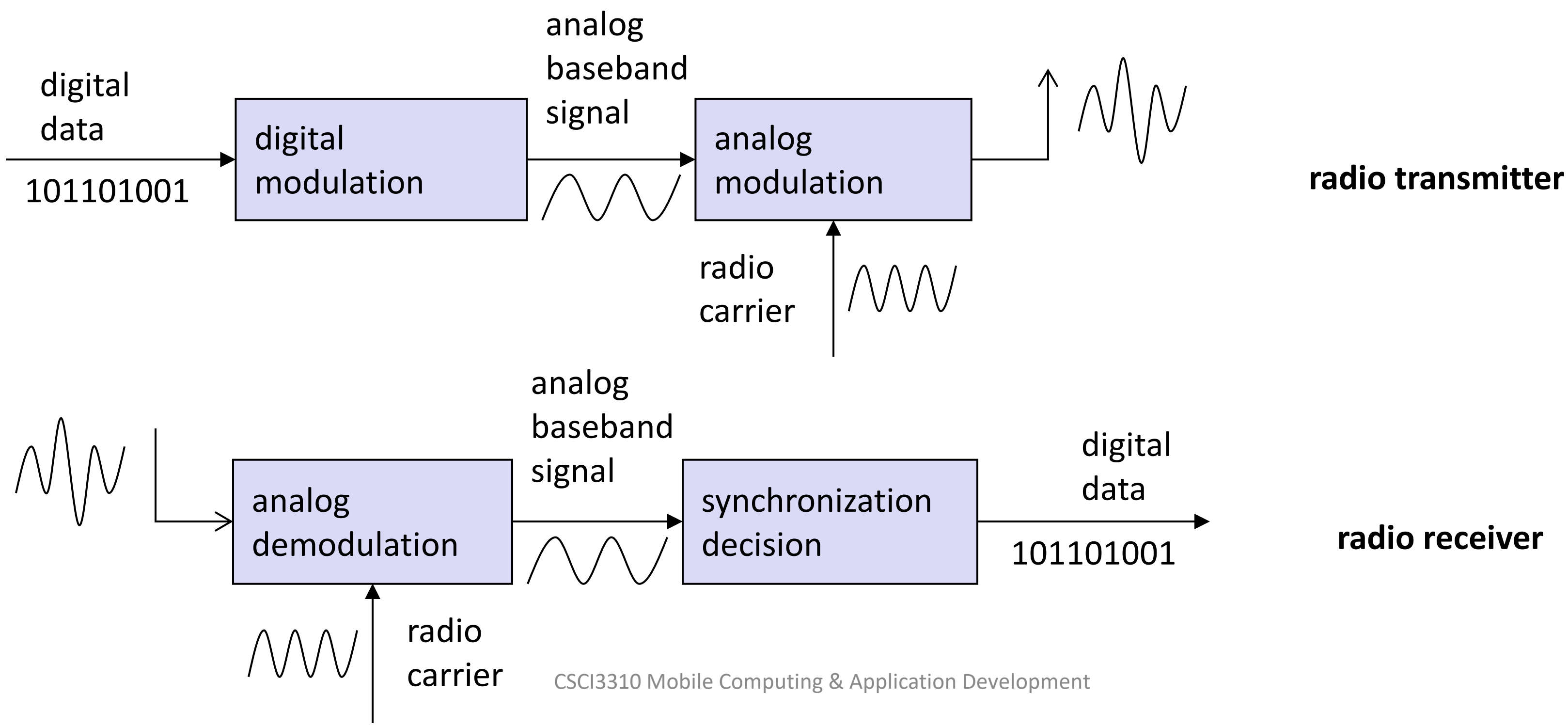
Wireless Communications

- The air-interface is shared by many different users & services
- Each service has a certain allocated frequency
- Carrier modulation is needed to occupy only the given spectrum

Examples:
FM Radio: 88 – 108 MHz
WLAN – 2.4 or 5 GHz
Cellular Radio: 806-890 MHz
GPS: 1215 – 1240 MHz

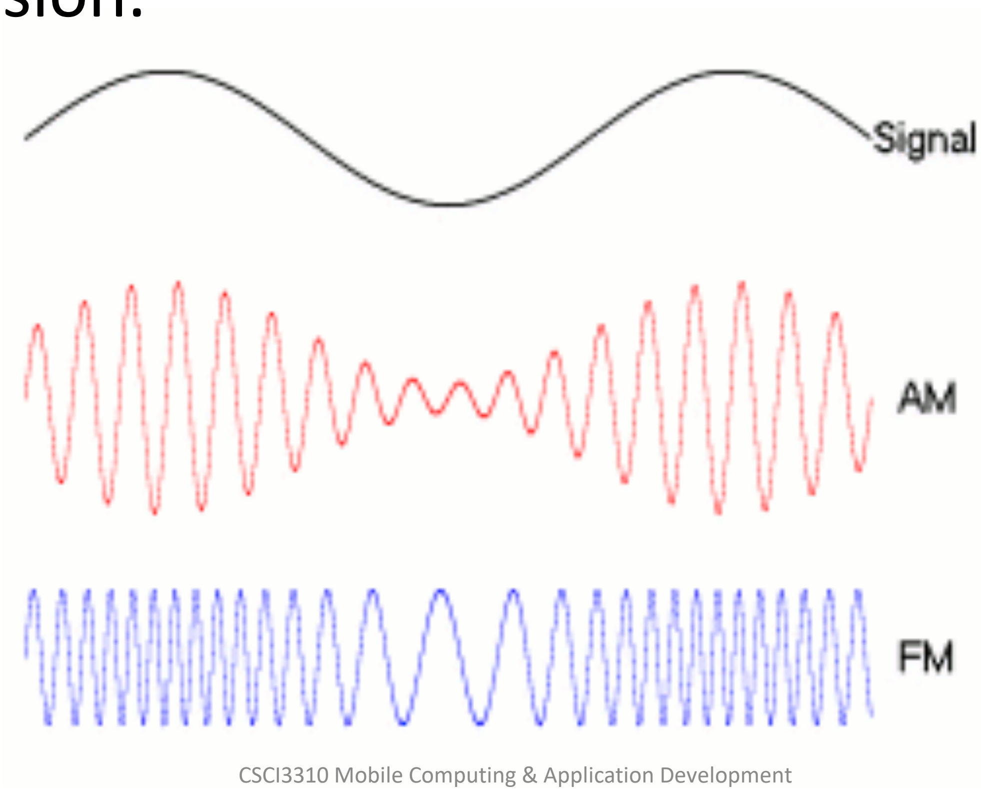
Modulation and demodulation

- **Modulation** is the process of varying one or more properties of a periodic waveform, called the *carrier signal*, with a modulating signal that typically contains information to be transmitted.



Analog Modulation

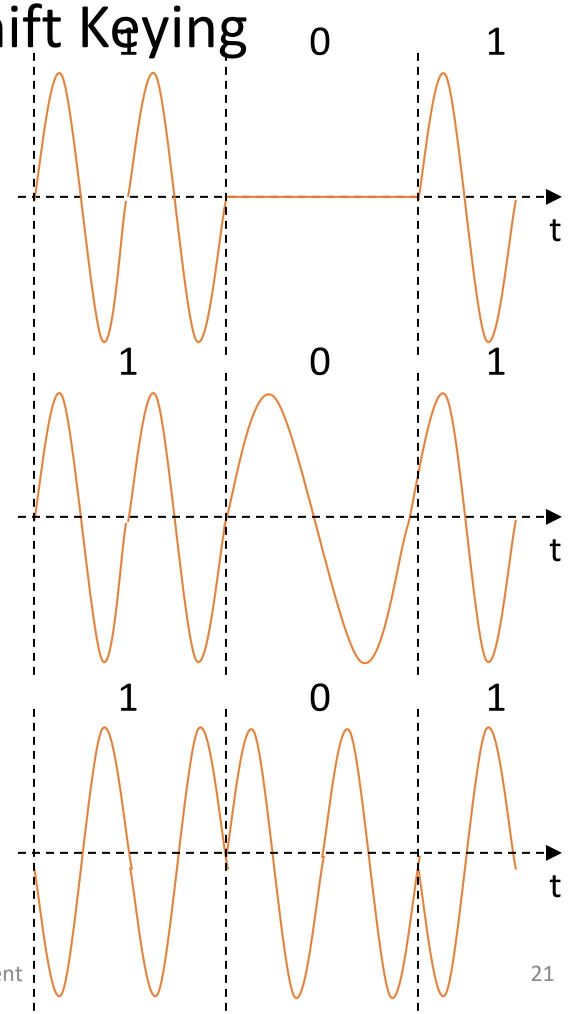
- **Analog Modulation** can vary amplitude, frequency of other properties of the *carrier signal* in transmission.



Digital Modulation

Modulation of digital signals known as Shift Keying

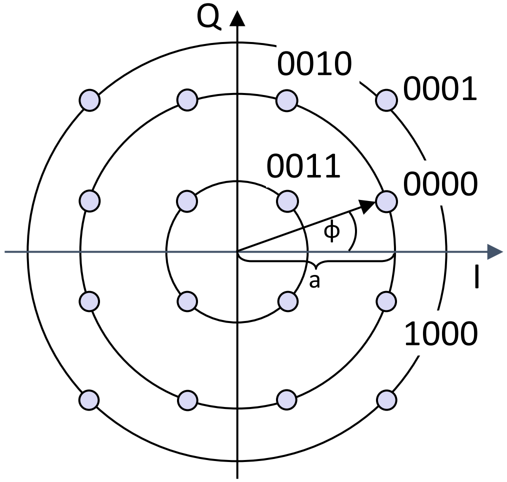
- **Amplitude Shift Keying (ASK):**
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- **Frequency Shift Keying (FSK):**
  - needs larger bandwidth
- **Phase Shift Keying (PSK):**
  - more complex
  - robust against interference



Quadrature Amplitude Modulation

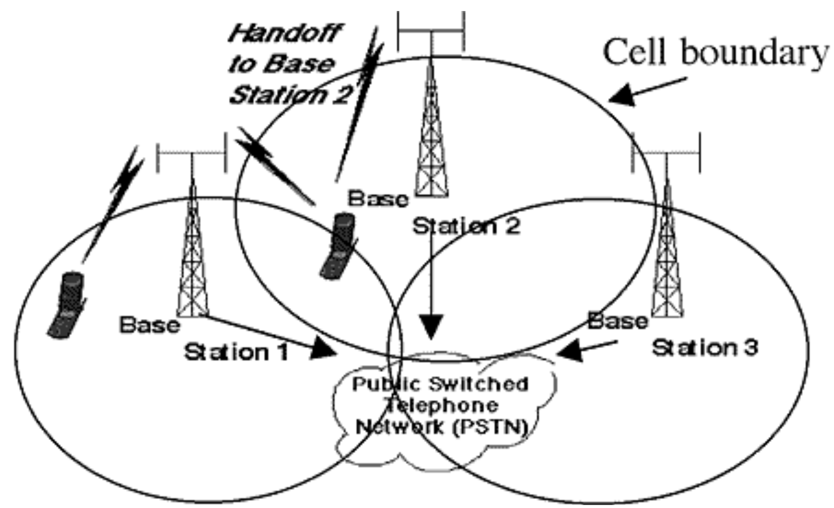
- **Quadrature Amplitude Modulation (QAM)**
  - combines amplitude and phase modulation
  - it is possible to code n bits using one symbol
  - 2^n discrete levels, n=2 identical to QPSK

- Bit error rate increases with n, but less errors compared to comparable PSK schemes
  - Example: 16-QAM (4 bits = 1 symbol)
  - Symbols 0011 and 0001 have the same phase φ, but different amplitude a. 0000 and 1000 have different phase, but same amplitude.



Cellular Network

- Base stations transmit to and receive from mobiles at the assigned spectrum
  - Multiple base stations use the same spectrum (spectral reuse)
  - The service area of each base station is called a cell
- Each mobile terminal is typically served by the 'closest' base stations
  - Handoff when terminals move



The Multiple Access Problem

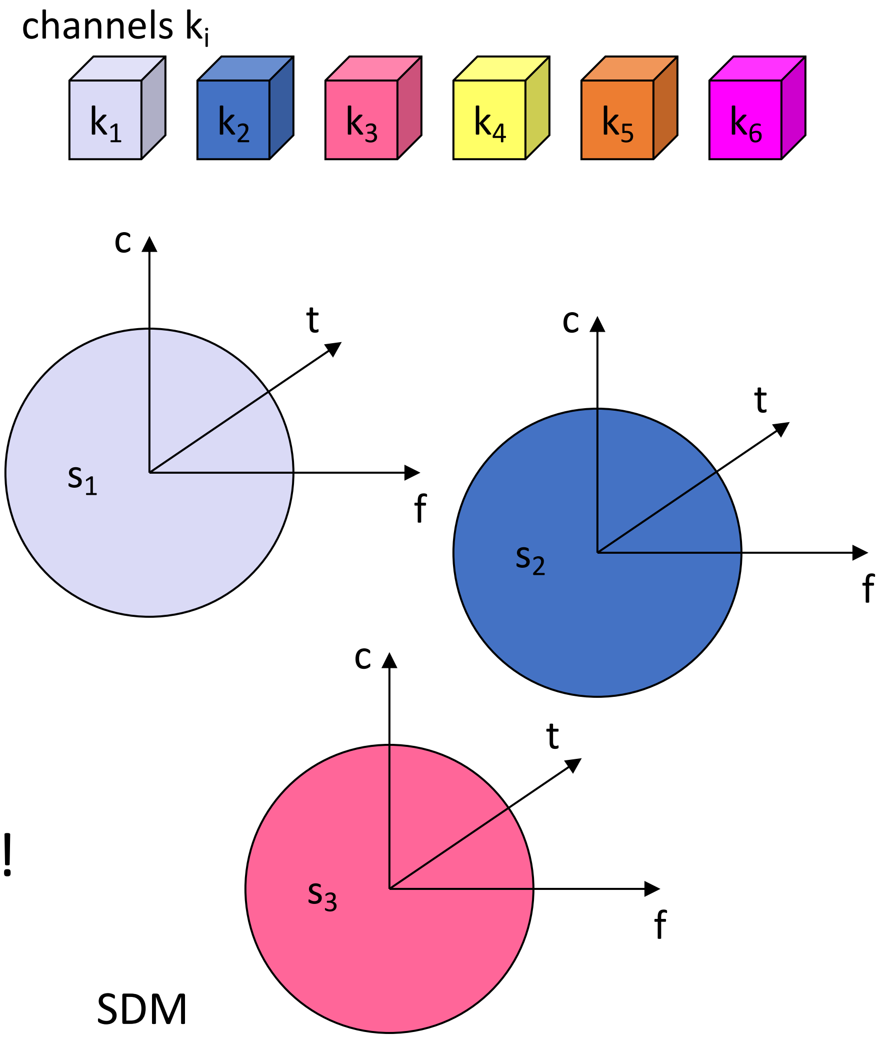
- The base stations need to serve many mobile terminals at the same time (both downlink and uplink)
- All mobiles in the cell need to transmit to the base station
- Interference among different senders and receivers
- So we need multiple access (also named multiplexing) scheme

Multiplexing Schemes

- **Multiplexing in 4 dimensions**
  - **space (s_i)**
  - **time (t)**
  - **frequency (f)**
  - **code (c)**

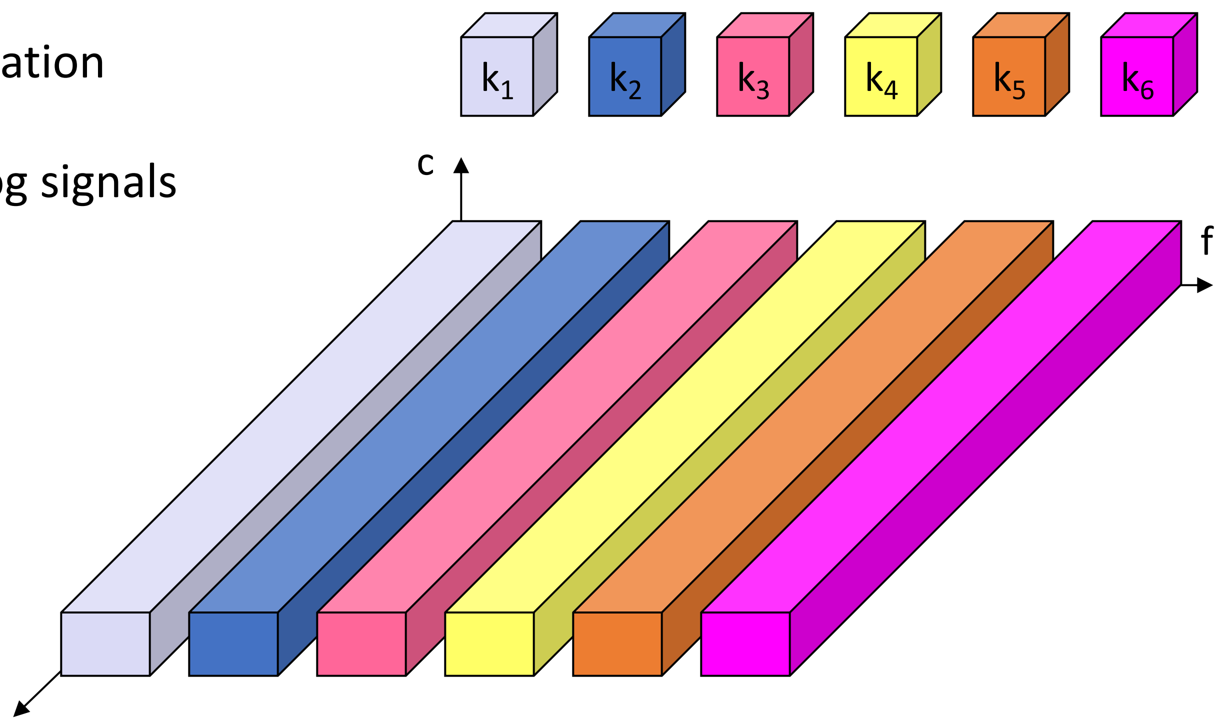
- Goal: multiple use of a shared medium

- Important: guard spaces needed!



Frequency division multiplexing (FDM)

- Separation of the whole spectrum into **smaller frequency bands**
- A channel gets a certain band of the spectrum for the whole time
- Advantages
  - no dynamic coordination necessary
  - works also for analog signals
- Disadvantages
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible

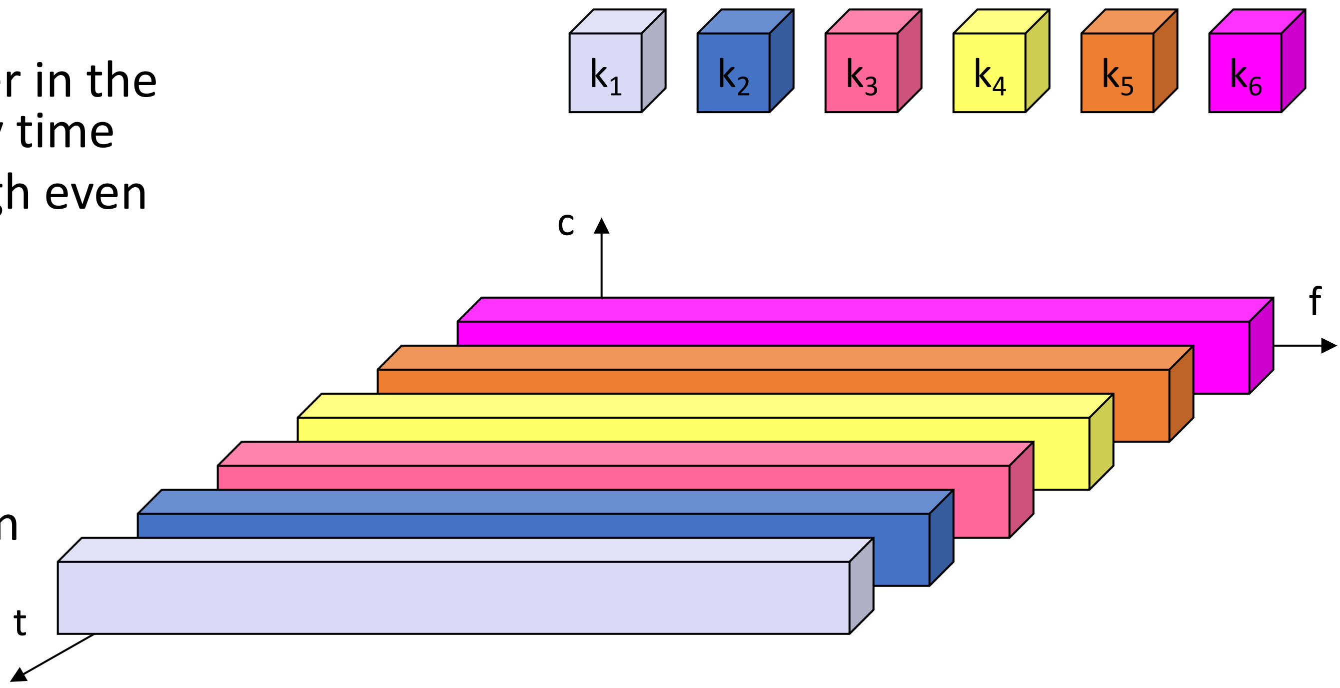


Time division multiplexing (TDM)

- A channel gets the whole spectrum for a **certain amount of time**

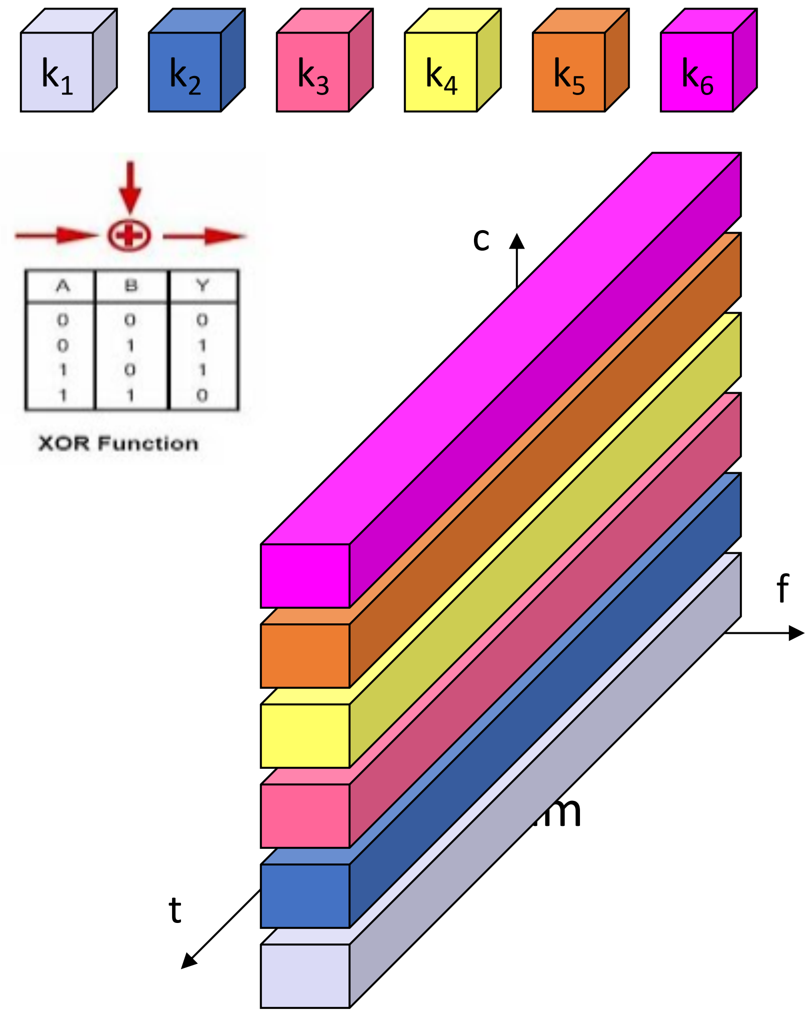
- Advantages
  - only one carrier in the medium at any time
  - throughput high even for many users

- Disadvantages
  - precise synchronization necessary



Code Division Multiplexing (CDM)

- Each channel has **unique code**
- All channels use the same spectrum at the same time
- Advantages
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages
  - varying user data rates
  - more complex signal regeneration
- Implemented using spread technology



References

Suggested Reading

- Chapter 11. Ubiquitous Communication, Smart Devices, Environments and Interactions, Stefan Poslad, Wiley

- Chapter 1. Mobile Computing, Raj Kamal, Oxford Higher Education, Second Edition

- https://en.wikipedia.org/wiki/Wireless