CSE 4215/5431: <u>Mobile Communications</u>

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Course page: http://www.cse.yorku.ca/course/4215

Some slides are adapted from the Schiller book website

The Physical Layer – Ch 2

- Let’s start with the very basic notions

Signals, channels and systems

- What is a signal?
  - Baseband signal
  - Modulation
  - Bandwidth
  - Transmission/reception
- What is a channel?
  - Bandwidth
  - Noise
  - Attenuation,Loss
- What is a communication system?

Types of signals

(a) continuous time/discrete time

(b) continuous values/discrete values

- analog signal = continuous time, continuous values
- digital signal = discrete time, discrete values

- Periodic signal - analog or digital signal that repeats over time
  - $s(t+T) = s(t) \quad -\infty < t < +\infty$
    - where T is the period of the signal
- signal parameters of periodic signals:
  period T, frequency f=1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

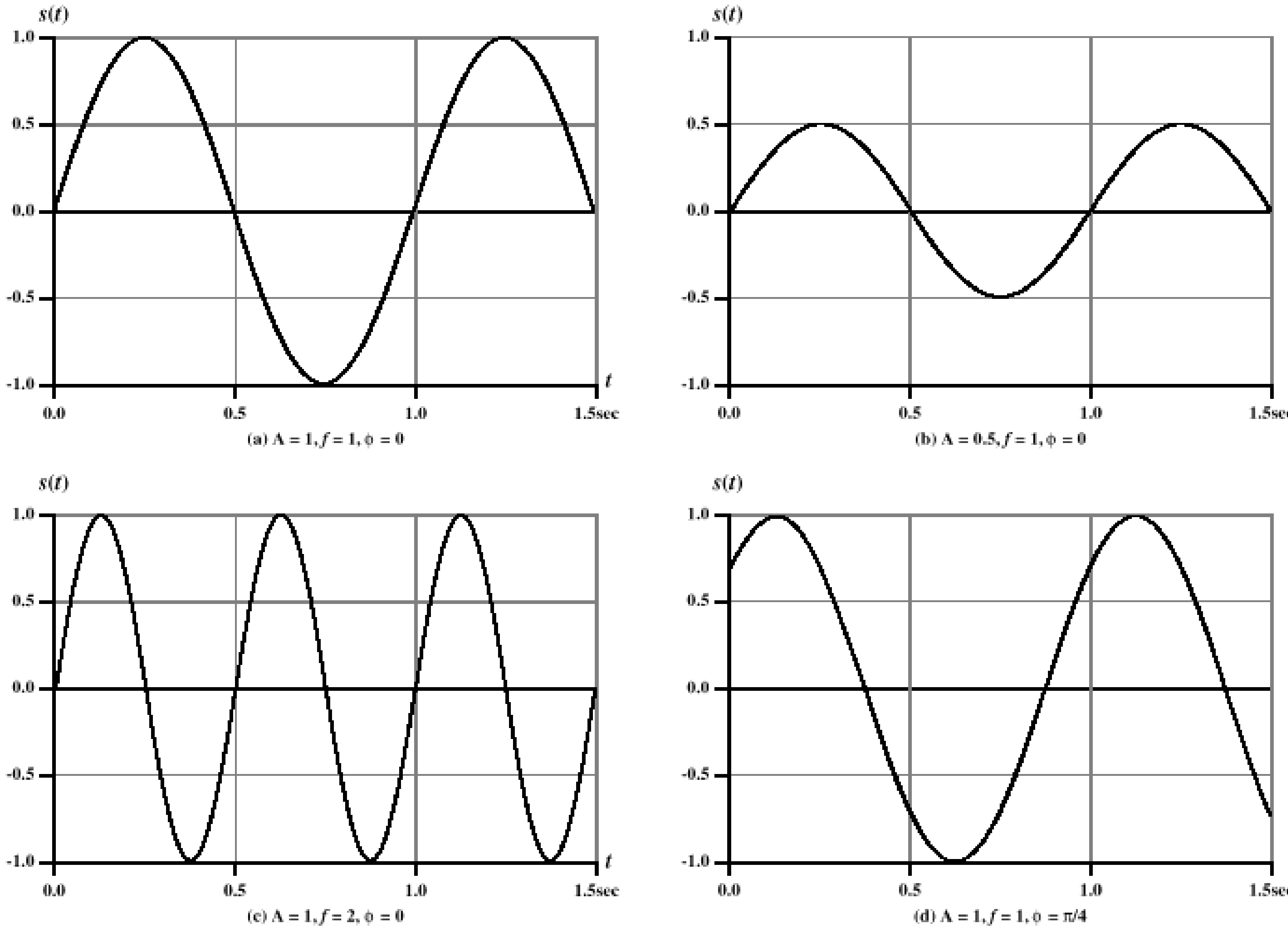


Figure 2.3 $s(t) = A \sin (2 \ ft + \phi)$

Bandwidth

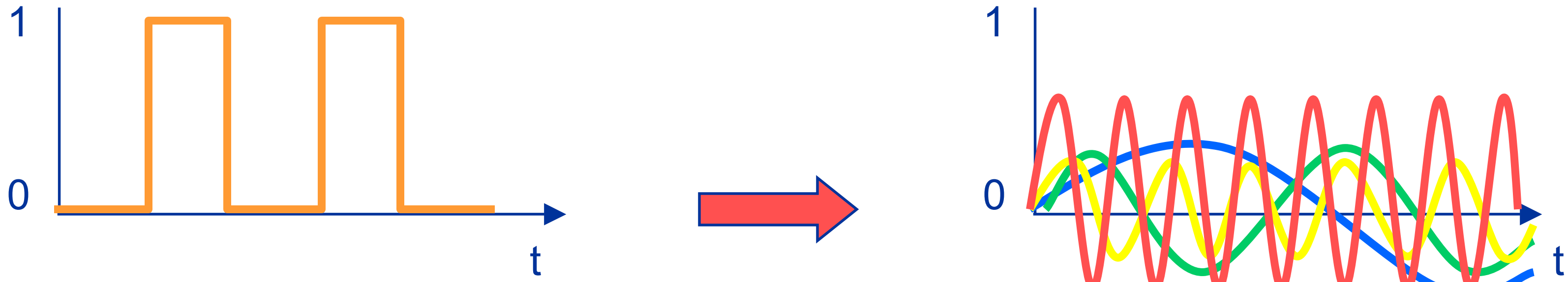
- Of a signal
- Of a channel

Bandwidth vs bit rate

The underlying mathematics

Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



ideal periodic signal

real composition
(based on harmonics)

What about aperiodic signals ?

Frequency domain

- Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
- Spectrum - range of frequencies that a signal contains
- Absolute bandwidth - width of the spectrum of a signal
- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in

Transmitting rectangular signals

- Observations
  - Any rectangular waveform will have infinite bandwidth
  - BUT the transmission system will limit the bandwidth that can be transmitted
  - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost
  - HOWEVER, limiting the bandwidth creates distortions

Bit rates, channel capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions

Nyquist Bandwidth

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\mathrm{dB}} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate

Shannon Capacity Formula

- Equation:

$$C = B\log_2\left(1 + \mathrm{SNR}\right)$$

- Represents theoretical maximum that can be achieved
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Example of Nyquist and Shannon Formulations

- Spectrum of a channel between 3 MHz and 4 MHz ; SNR_{dB} = 24 dB

$$B = 4\ \text{MHz} - 3\ \text{MHz} = 1\ \text{MHz}$$

$$\text{SNR}_{\text{dB}} = 24\ \text{dB} = 10\log_{10}(\text{SNR})$$

$$\text{SNR} = 251$$

- Using Shannon's formula

$$C = 10^6 \times \log_2(1+251) \approx 10^6 \times 8 = 8\text{Mbps}$$

Example of Nyquist and Shannon Formulations

- How many signaling levels are required?

$$C = 2B\log_2 M$$

$$8\times 10^6 = 2\times\left(10^6\right)\times\log_2 M$$

$$4 = \log_2 M$$

$$M = 16$$

Modulation

- Why?
- How?

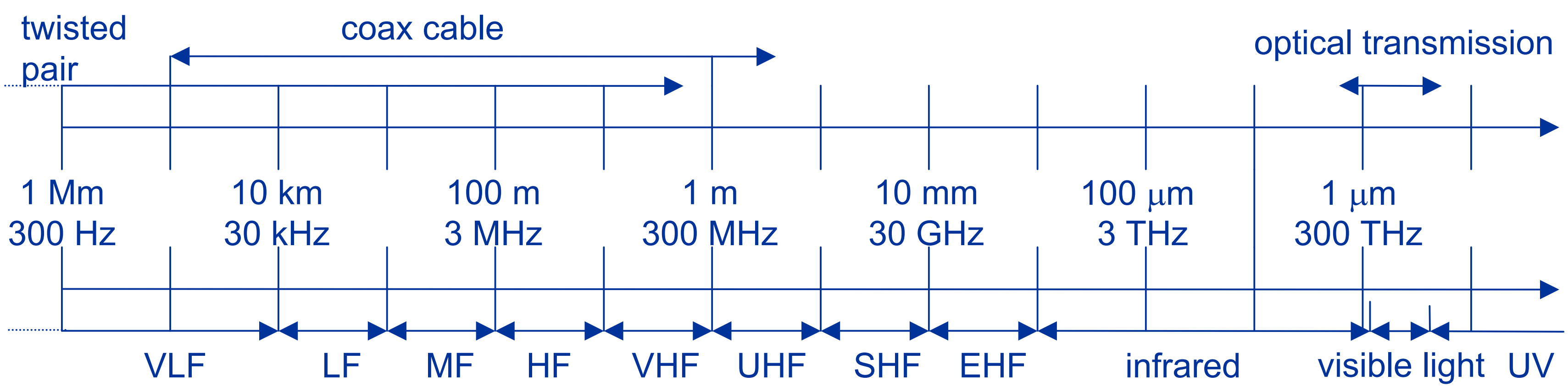
Frequencies for wireless communication

- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency

UV = Ultraviolet Light

- Frequency and wave length
  - $\lambda = c/f$
  - wave length λ, speed of light $c \cong 3x10^8 m/s$, frequency f



Frequencies for wireless communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, beam forming
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF range
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Frequencies and regulations

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

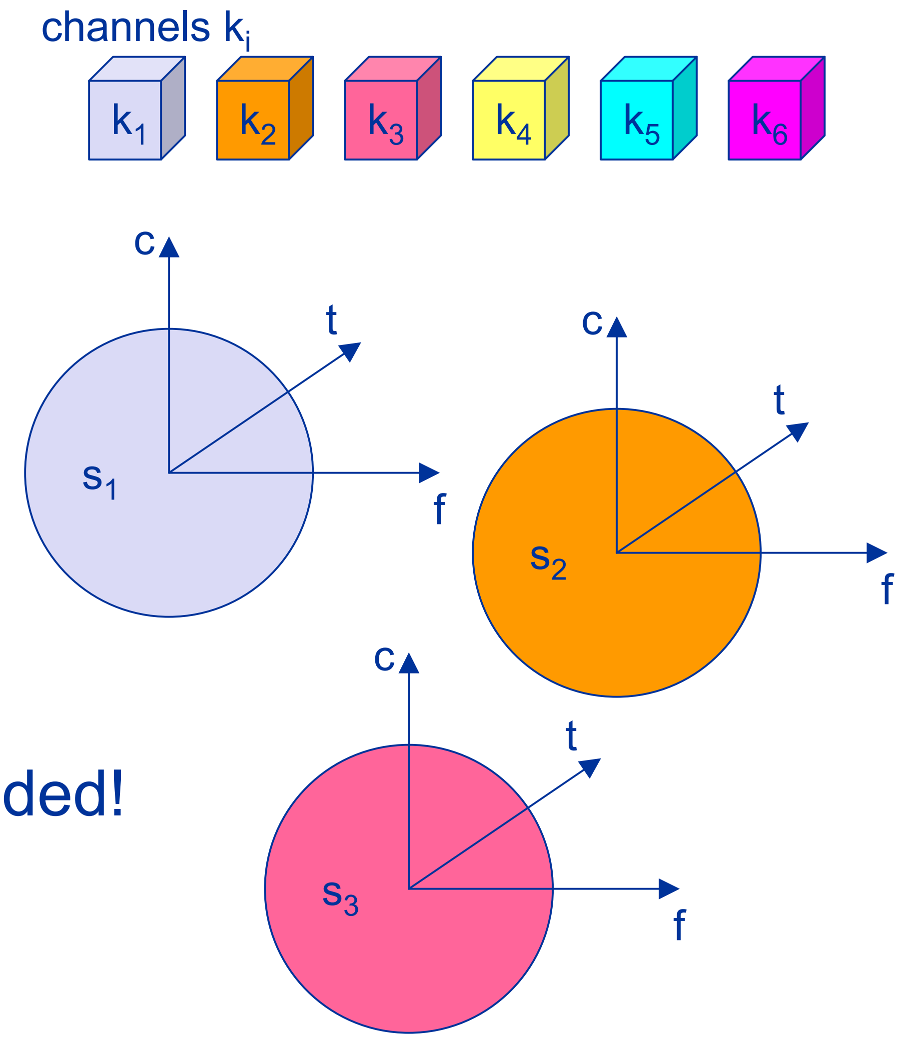
Examples	Europe	USA	Japan
Cellular phones	**GSM** 880-915, 925-960, 1710-1785, 1805-1880 **UMTS** 1920-1980, 2110-2170	**AMPS, TDMA, CDMA, GSM** 824-849, 869-894 **TDMA, CDMA, GSM, UMTS** 1850-1910, 1930-1990	**PDC, FOMA** 810-888, 893-958 **PDC** 1429-1453, 1477-1501 **FOMA** 1920-1980, 2110-2170
Cordless 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

Multiplexing

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

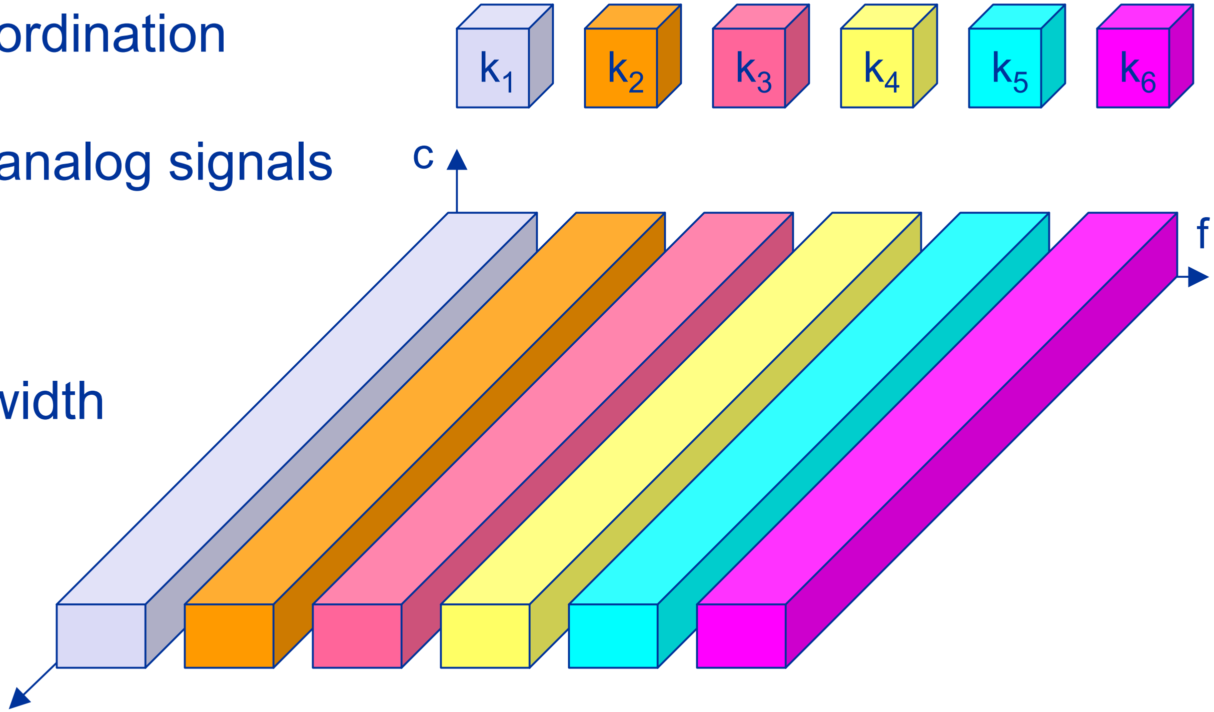
- Goal: multiple use of a shared medium

- Important: guard spaces needed!



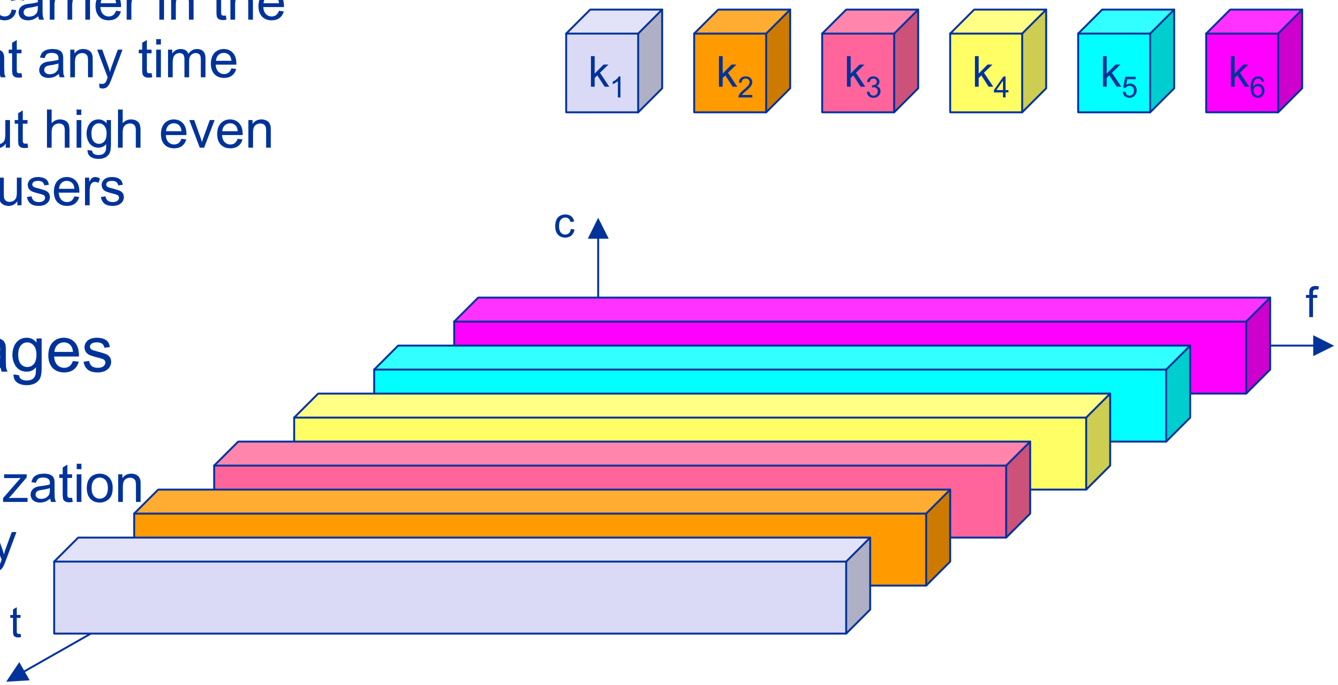
Frequency multiplexing

- 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

- 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



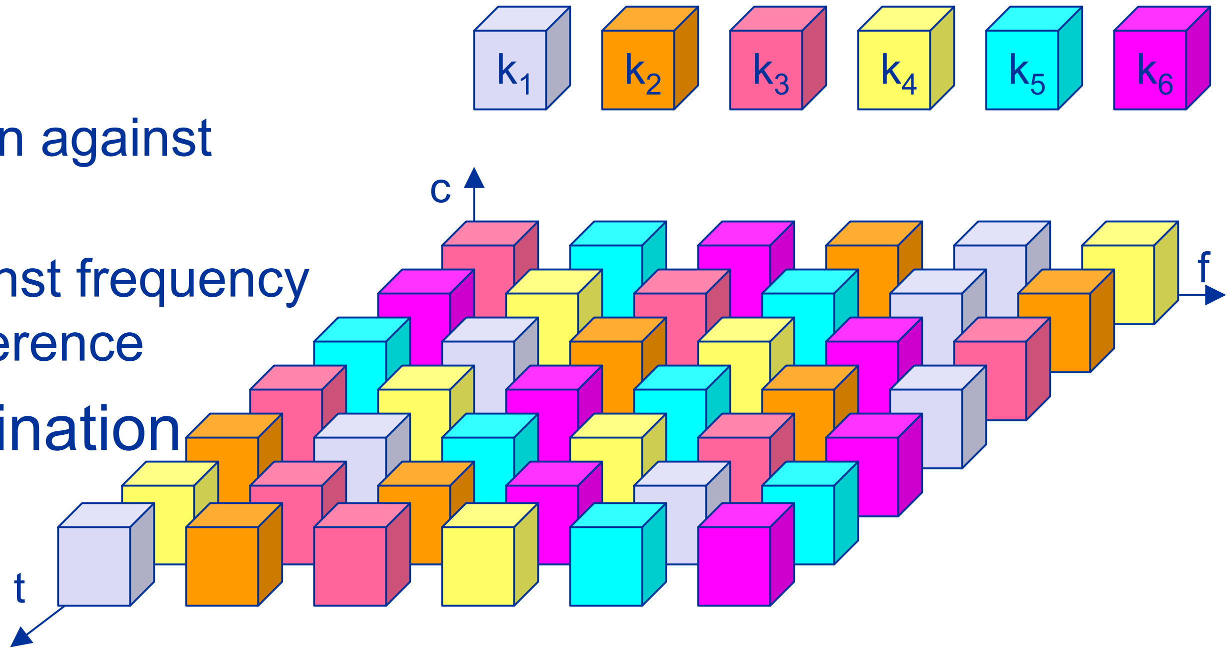
Time and frequency multiplex

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time
- Example: GSM

Advantages

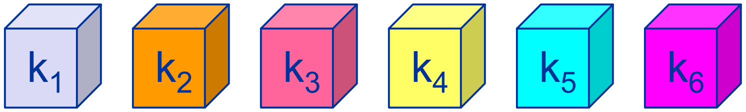
- better protection against tapping
- protection against frequency selective interference

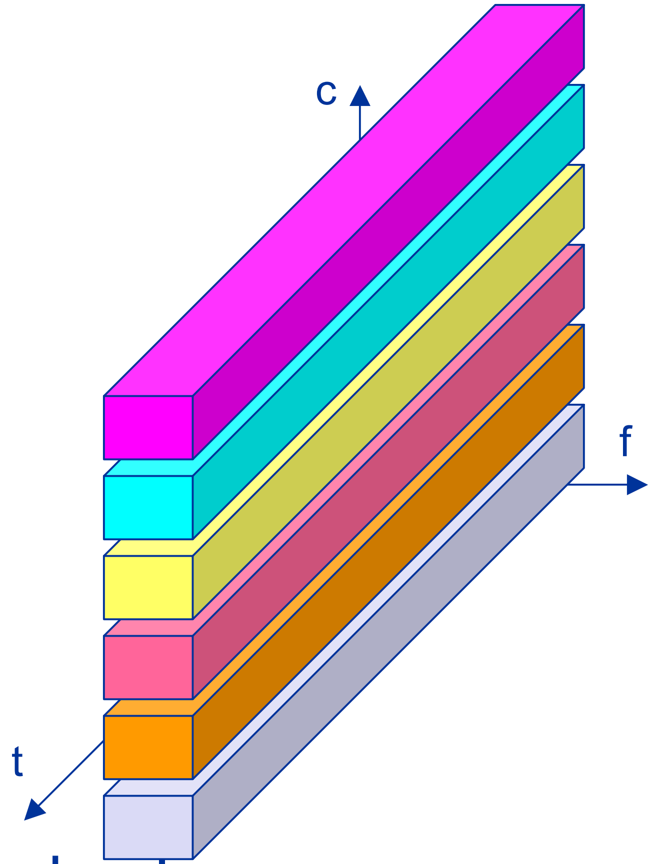
but: precise coordination required



Code multiplex

- Each channel has a unique code

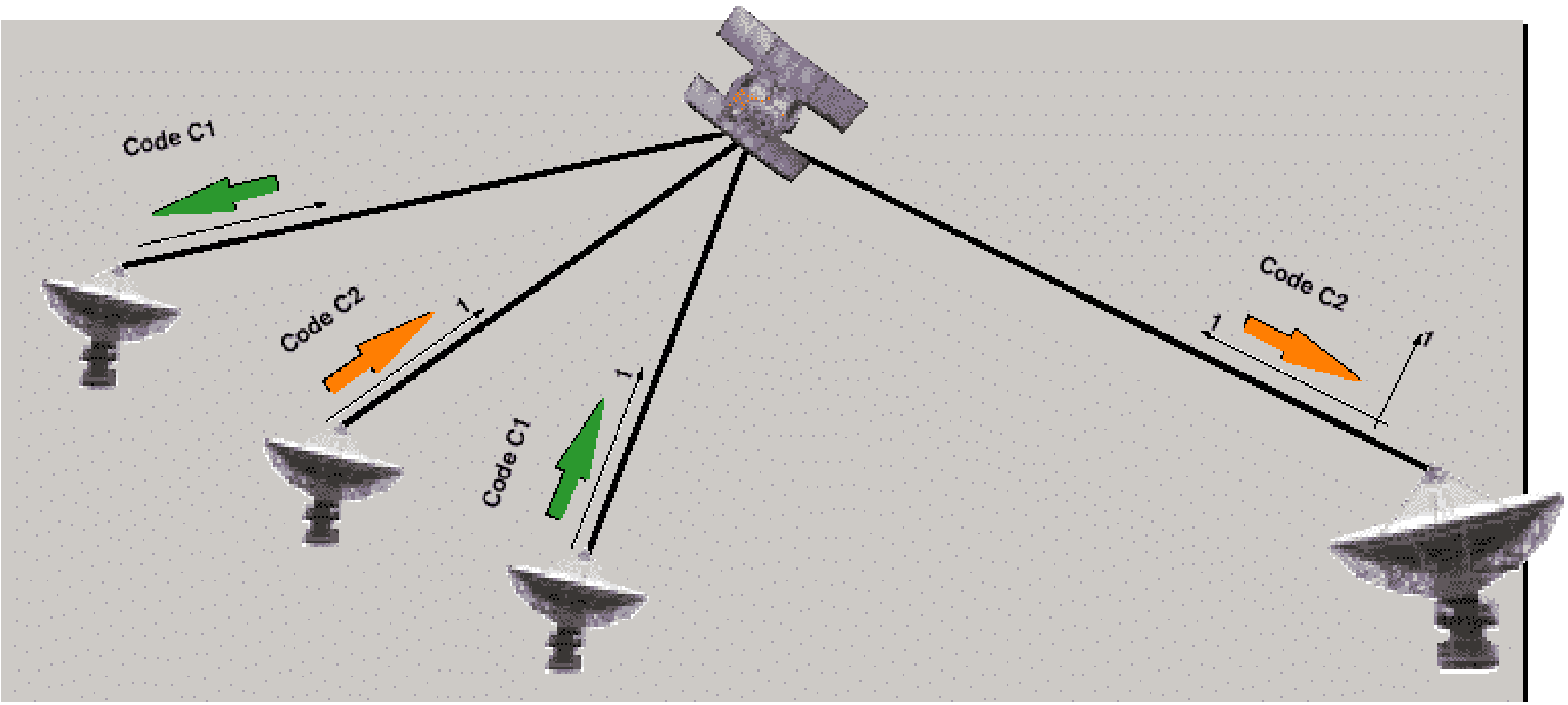




- All channels use the same spectrum at the same time
- Advantages
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages
  - varying user data rates
  - more complex signal regeneration
- Implemented using spread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

Example

- Lack of coordination requirement is an advantage.



Aside: Digital Communications

- What is coding?
- What is source coding?
- What are line codes?
- What is channel coding?
- What is pulse shaping?