Outline

- A preliminary overview
- Propagation characteristics
- ISO-OSI Model
- Physical layer: modulation
- **MAC layer:**
  - **Fixed resource assignment**
  - Random access
    - Ethernet (CSMA/CD)
    - WiFi (CSMA/CA)
- Personal Area Networks
  - Bluetooth
  - Zigbee
- Cellular network dimensioning
- Cellular networks
  - From GSM (2G) to UMTS (3G)
  - LTE (4G)

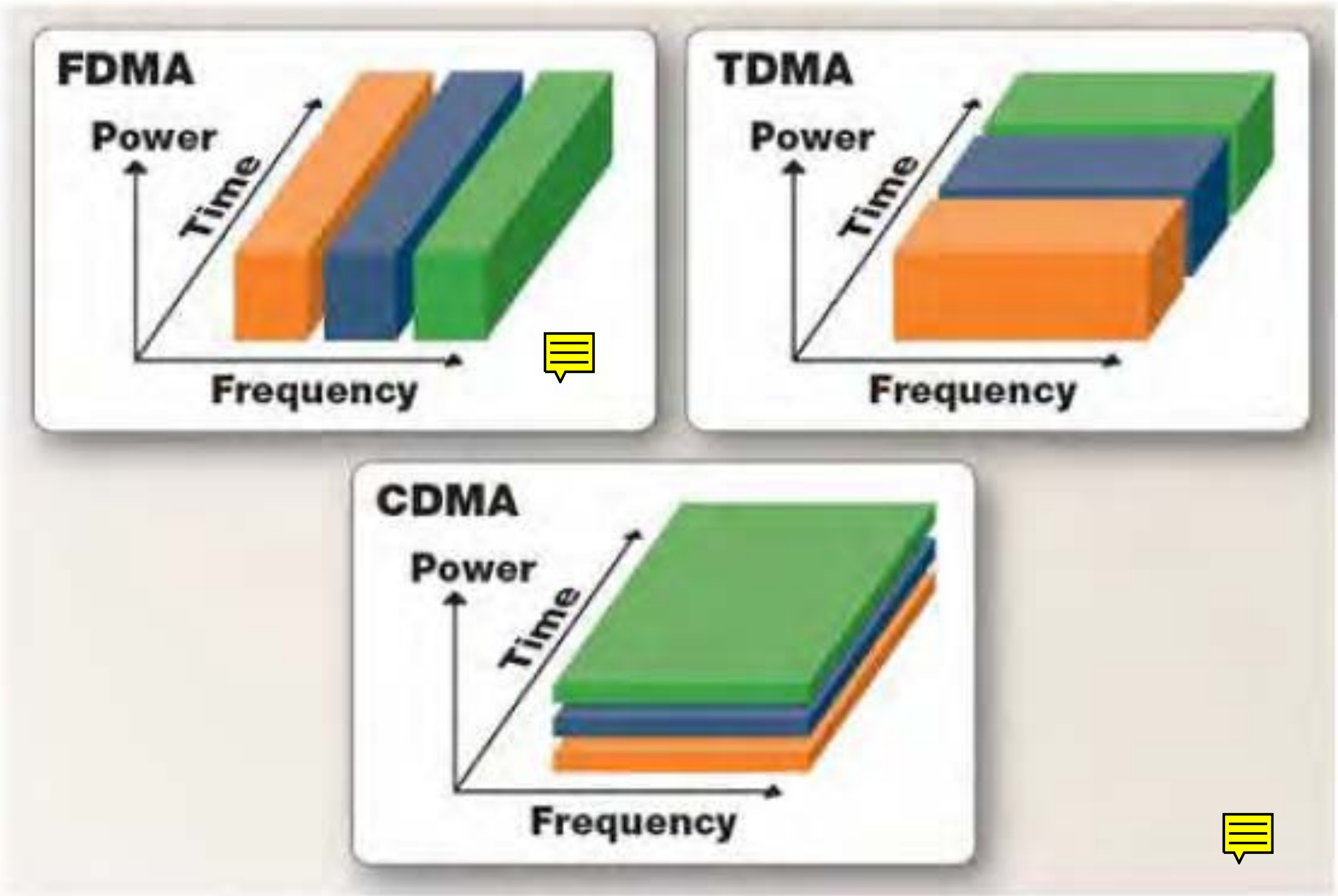
Wired vs. Wireless LANs

- The first approach was to apply the same MAC protocols for wired networks (e.g., IEEE 802.3 with CSMA/CD) to wireless networks.
- There are, however, two main differences:
  - available bandwidth;
  - transmission reliability.
- It is not possible to duplicate the shared medium, i.e., the air.
- If something goes wrong, it may be due to fading and not collisions.

Reservation-Based Approaches

- Suitable for voice-oriented applications.
- Reservation can be done by signaling channels.
- It is necessary for (possible) long conversations.
- Three possible quantities can be reserved:
  - time slots (TDMA), as in GSM;
  - frequency bands (FDMA), as in GSM;
  - expansion codes (CDMA), as in UMTS.
- Other (random access) techniques may be used for various reasons (see, e.g., slotted Aloha in GSM).

TDMA, FDMA, CDMA



DSSS e CDMA

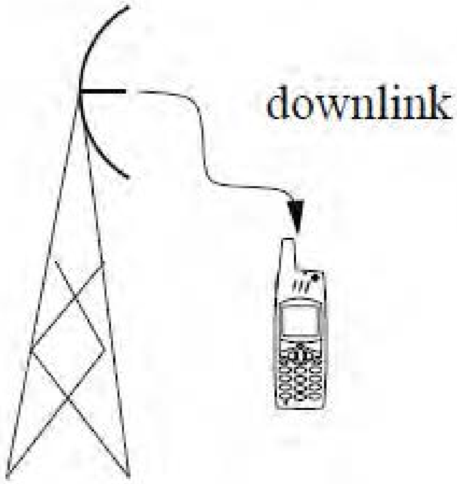
- <u>Alla lavagna</u>:
  - – Modulazione a spettro espanso
  - – Direct sequence spread spectrum
  - – Sistemi CDMA con interferenza da accesso multiplo

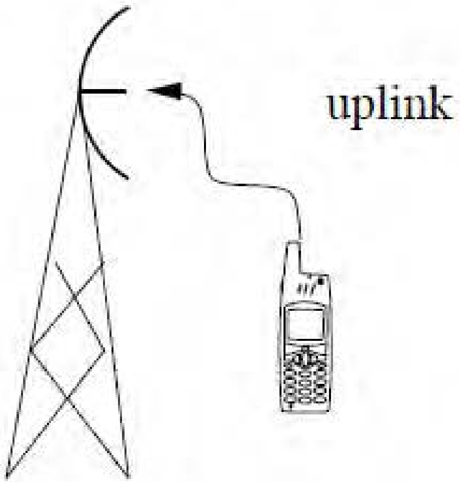
P. M. Shankar, *Introduction to Wireless Systems*, Wiley, 2001, ISBN-13: 978-0471321675.

Uplink vs. Downlink

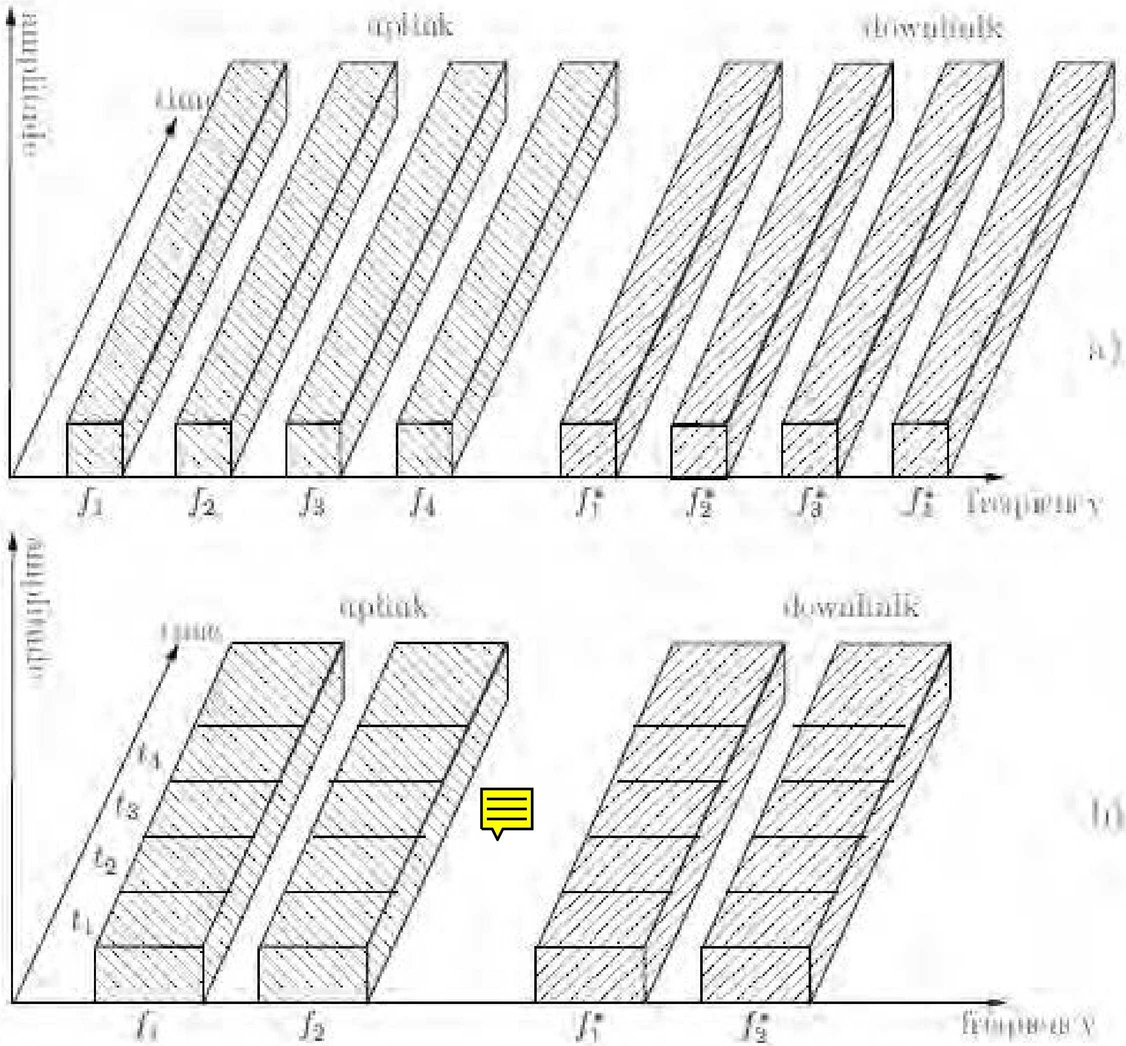
- Time Division Duplex (TDD): the two channels use the same carrier frequency and, therefore, it is necessary to alternate time slots.

- Frequency Division Duplex (FDD): the two channels use separate carrier frequencies and, therefore, they can operate during the same time slots.



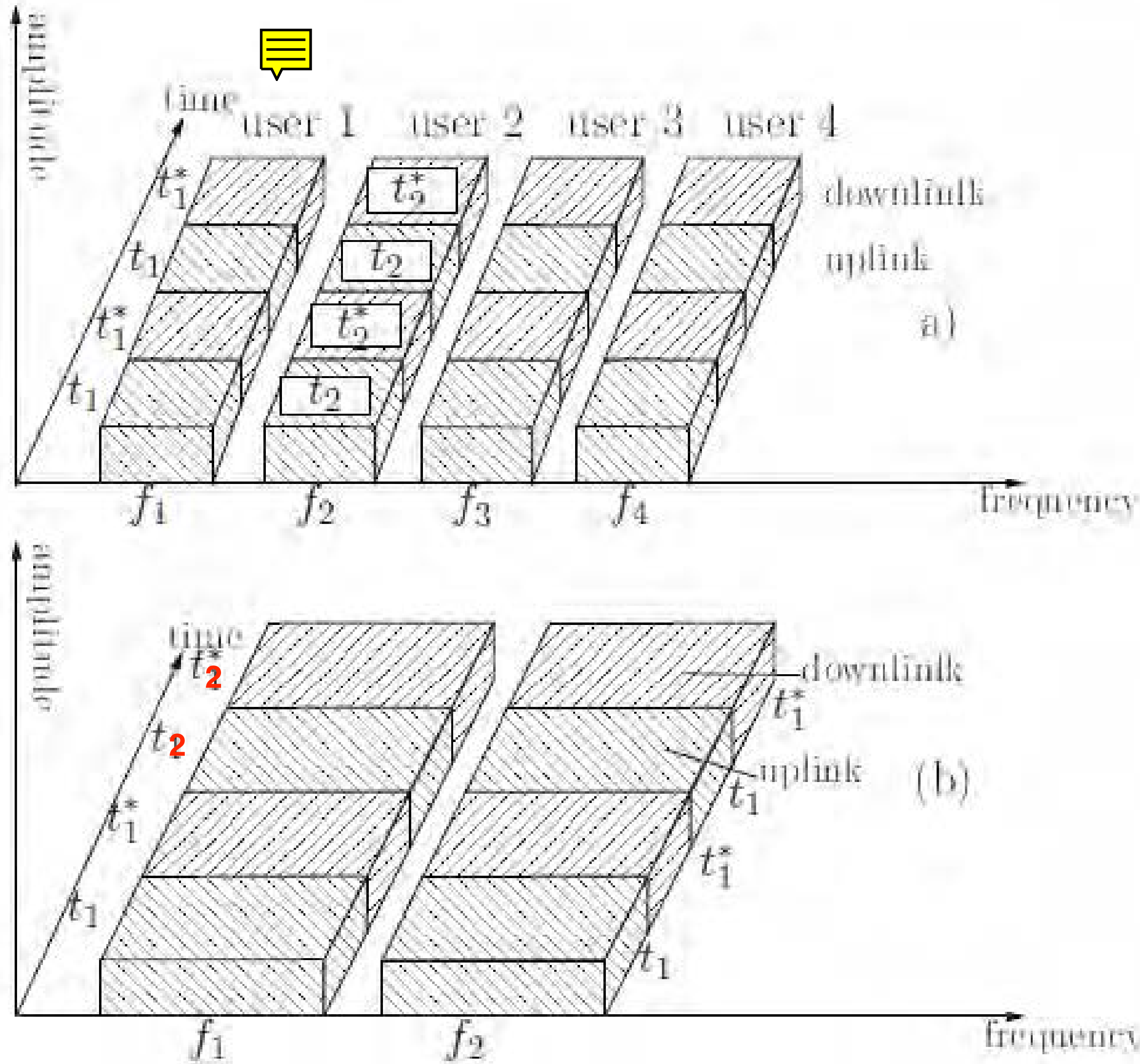


FDD



amplitude
uplink
downlink
time
a)
f_1 f_2 f_3 f_4 f_1^* f_2^* f_3^* f_4^* frequency
amplitude
uplink
downlink
time
t_1 t_2 t_3 t_4
b)
f_1 f_2 f_1^* f_2^* frequency

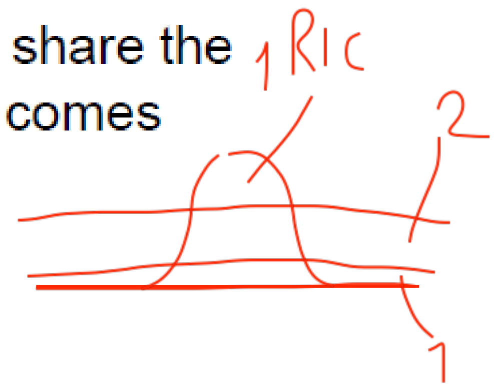
TDD



amplitude
time
user 1
user 2
user 3
user 4
t_1^*
t_1
t_1^*
t_1
t_2^*
t_2
t_2^*
t_2
downlink
uplink
a)
f_1
f_2
f_3
f_4
frequency
amplitude
time
t_2^*
t_2
t_1^*
t_1
downlink
t_1^*
uplink
t_1
(b)
t_1^*
t_1
f_1
f_2
frequency

CDMA

- Attractive since it is possible to mix different users without any specific coordination.
- Power control becomes essential, since all users share the same bandwidth. In other schemes, interference comes from adjacent (time or frequency) channels.



- Use of spread spectrum modulation:

$$\underbrace{B}_{\text{bandwidth}} = \underbrace{g}_{\text{spreading factor}} \cdot \underbrace{R_{\mathrm{b}}}_{\text{bit rate}}$$

$$\underbrace{P_{\mathrm{s}}}_{\text{signal power}} = \underbrace{g}_{\text{spreading factor}} \cdot \underbrace{P_{\mathrm{r}}}_{\text{received power}}$$

$$\underbrace{P_{\mathrm{int}}}_{\text{interference power}} = \underbrace{N-1}_{\text{interferers}} \cdot \underbrace{P_{\mathrm{r}}}_{\text{received power}}$$

Number of Active Users (I)

- The Signal-to-Noise Ratio (SNR) is

$$\mathrm{SNR} = \frac{P_{\mathrm{s}}}{P_{\mathrm{th}} + P_{\mathrm{int}}}$$

  with thermal noise $P_{\mathrm{th}} = FkT_0R_{\mathrm{b}}$, where: F is the noise figure; $k = 1.38 \cdot 10^{-23}$ J/K is the Boltzmann constant; and $T_0 = 290$ K.

- Supposing that the thermal noise is negligible with respect to interference, one obtains:

$$\mathrm{SNR} \simeq \frac{P_{\mathrm{s}}}{P_{\mathrm{int}}} = \frac{gP_{\mathrm{r}}}{(N-1)P_{\mathrm{r}}}$$

  i.e., with ideal power control, the SNR does not depend on the receive power.

- If $N \gg 1$, then

$$\mathrm{SNR} \simeq \frac{g}{N} = \frac{B}{R_{\mathrm{b}}N}.$$

Number of Active Users (II)

- Suppose to require a given Quality of Service (QoS):

$$\mathrm{SNR} \geq \mathrm{SNR}_{\min}$$

  where $\mathrm{SNR}_{\min}$ depends on the specific application.
- At this point, it easy to obtain

$$N \leq \frac{B}{R_{\mathrm{b}}\mathrm{SNR}_{\min}} = N_{\max}.$$

- In the presence of TDMA or FDMA, the capacity is simply given by the number of allocated time slots or frequency bands.

Maximum Number of Sustainable Users

$$N_{\max} \simeq \frac{B}{R_b \mathrm{SNR}_{\min}} \times K$$

where K is a performance improvement factor[1] given by

$$K = \frac{G_A G_\nu}{H_O}.$$

- G_A: sectorization gain factor; for three sector antennas, $G_A = 2.5 < 3$ due to reflections.
- G_ν: voice activity factor; for instance, if voice flows have pauses for almost 60% of time, then $G_\nu = 2.5$.
- H_O: interference factor due to adjacent cells; a possible value is $H_O = 1.6$ dB.

[1] Note that k is the Boltzmann constant and K is the performance improvement factor.

Rumore termico

- <u>Alla lavagna</u>:
  - – Rumore termico
  - – Temperatura equivalente di rumore
  - – Cifra di rumore
  - – Sensitività di un ricevitore

S. Haykin e M. Moher, *Modern Wireless Communications*, Prentice Hall, 2004, ISBN-13: 978-0130224729.

C/T/F-DMA Comparison: Format Flexibility

- TDMA is more flexible than FDMA, since dynamic slot allocation is possible; however, TDMA suffers of synchronization problems.

- In CDMA, it is possible to easily set different QoS to each user and there is no need to synchronize nodes (quasi-orthogonal spreading sequences are good codes).

C/T/F-DMA Comparison: Multipath Fading

- FDMA is a narrow-band system and can suffer from holes in the power spectral density.

- CDMA takes advantage of spreading by using the portion of the transmission bandwidth which is not corrupted by fading.

- GSM/IS-~~36~~136: $B_c = 200$ kHz/30 kHz vs $B = 1250$ kHz.

- IS-95: $B_c = 1250$ kHz vs $B = 1250$ kHz.

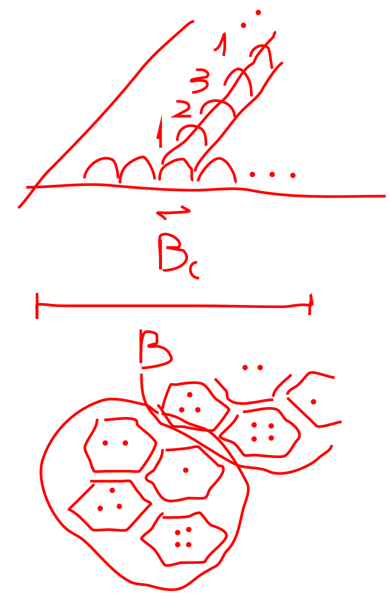
- Note that the carrier bandwidth may not be equal to data rate, due to the employed modulation.

C/T/F-DMA Comparison: System Capacity (1)

- For IS-136:

$$N_{\max} = \frac{B}{B_c}\underbrace{\frac{N_u}{K}} = \frac{1.25 \cdot 10^6}{30 \cdot 10^3}\frac{3}{4} \simeq 31 \text{ users/cell}$$

where N_u is the number of users per ~~cell~~ and K is the reuse factor.



- For IS-95:

$$N_{\max} \simeq \frac{B}{R_b \mathrm{SNR}_{\min}}\frac{G_A G_\nu}{H_O} = \frac{1.2510^6}{9.610^34}\frac{22.75}{1.6} \simeq 108 \text{ users/cell.}$$

C/T/F-DMA Comparison: System Capacity (2)

- For AMPS (FDMA):

$$N_{\max} = \frac{B}{B_c}\frac{1}{K} = \frac{1.25 \cdot 10^6}{30 \cdot 10^3}\frac{1}{7} \simeq 6\,\mathrm{users/cell}.$$

- For GSM:

$$N_{\max} = \frac{B}{B_c}\frac{N_u}{K} = \frac{1.25 \cdot 10^6}{200 \cdot 10^3}\frac{8}{7} \simeq 16\,\mathrm{users/cell}.$$

C/T/F-DMA Comparison: Hand-off (Horizontal Handover)

- For 1G (FDMA): base station controller (BSC) makes a "hard" switch.
- From 2G-TDMA: mobile-assisted handoff $\longrightarrow$ the mobile tells the BSC how the received signal strength varies.
- From 2G-CDMA: since adjacent cells use the same frequencies, there is a "seamless" (soft) handoff (provided that the same spreading code is available in the two cells).