UNIVERSITÀ DELLA CALABRIA

Master Degree in Telecommunications Engineering

“Mobile Radio Networks” Class

Introducing the Course

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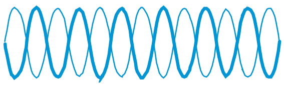
Goal of the course

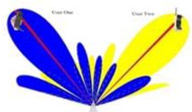
- Provide you the knowledge on the technology and network protocols of mobile radio networks, as well as on design and dimensioning methodology

- Cellular architectures
- Radio planning and networks design
- Signaling and control
- GSM, GPRS, UMTS, HSPA, LTE, 5G

Connections with other courses

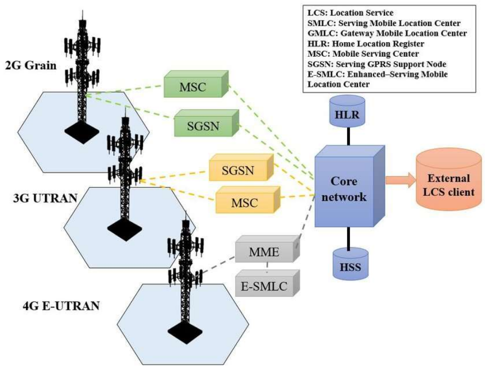
- Mobile radio networks are based on basic notions also introduced in other courses and make use of technologies deriving from various fields:
    - advanced transmission techniques (modulation techniques, protection techniques, equalization, receivers)
    - antennas and signal propagation (radio propagation, channel patterns, antennas)
    - digital signal processing techniques





Connections with other courses

- We are interested in the network as a system
    - Protocols
    - Services
    - Procedures



- ... but the system is strongly influenced by the particular transmission medium (wireless) which requires particular technologies.
  So, we will have to give some hints (we will do it during the exercise lessons).

Mobile Radio Networks course program

- Basic concepts
  - Introduction
  - Digital wireless communications
  - Cell dimensioning
  - Network planning tools
- Radio resources
  - Multiple access
  - Radio resource management
  - Traffic models
  - Channel reuse and network design optimization

Mobile Radio Networks course program

- Mobile Technologies
  - Architecture, signaling, network functions
  - GSM
    - Radio interface
    - Protocol architecture
    - Examples of signaling procedures
  - GPRS/EDGE
    - Resource management
    - Protocols
  - UMTS and HSPA (brief overview)
  - LTE, LTE-Advanced
    - Network architecture
    - Protocol architecture
    - Examples of signaling procedures
  - 5G
    - 5G: Service-Based Architecture
    - Overview of 5G radio access and core network
    - Slicing in 5G cellular systems
    - NTN in 5G cellular systems

Mobile Radio Networks

- Introduction

Why mobile systems?

- The primary purpose of a mobile radio system is to make possible an "anytime, anywhere" connection (connection between mobile users, between mobile users and the fixed network ....)
- The market had a strong development in the 80s and the demand is still growing rapidly.

Why mobile systems?

- Do you remember telephone booths?

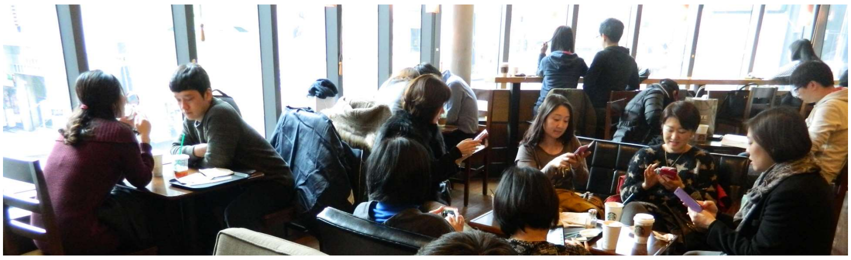
Why mobile systems?

- They have been part of everyday life
- Now they have been removed almost everywhere

Why mobile systems?

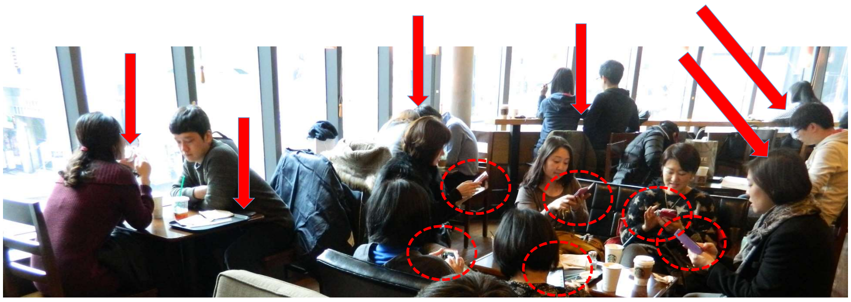
- They have been part of everyday life
- Now they have been removed almost everywhere

Now we cannot live without our smart phone



Starbucks Seoul

are we exaggerating?



Starbucks Seoul

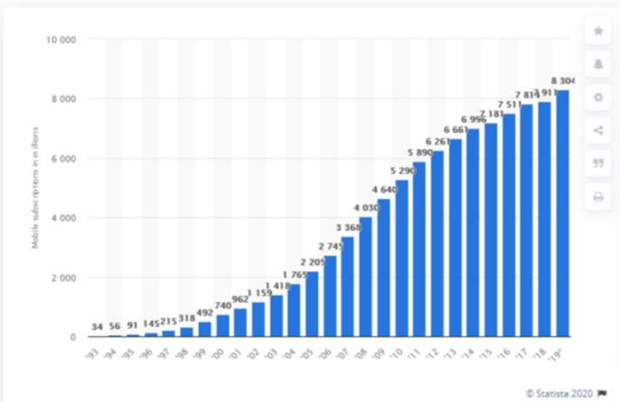
Now we cannot live without our smart phone

Seoul Metro

are we exaggerating?

Mobile network subscribers

Mobile subscriptions worldwide outnumbered the World’s population in 2014



Percentage of people online worldwide

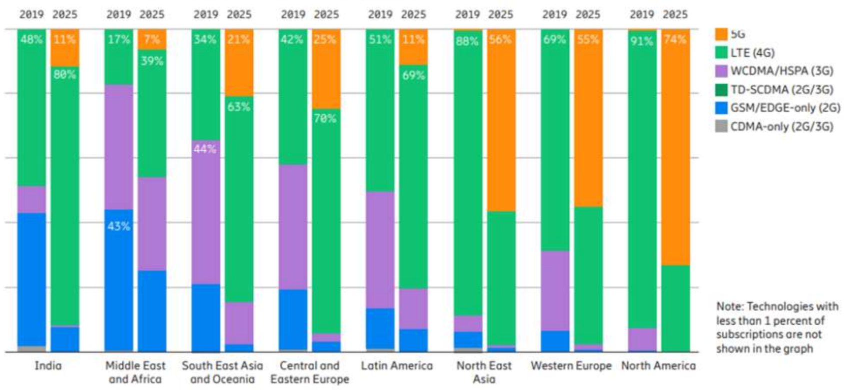
Figure 1: Subscription penetration Q3 2019 (percent of population)

[1] Mobile broadband includes radio access technologies HSPA (3G), LTE (4G), 5G, CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX
[2] Mainly CDMA2000 EV-DO, TD-SCDMA and Mobile WiMAX
* India region includes India, Nepal and Bhutan
** Excluding China and India

Source: Ericsson Mobility Report

Percentage of people online worldwide

Figure 9: Mobile subscriptions by region and technology (percent)



Source: Ericsson Mobility Report

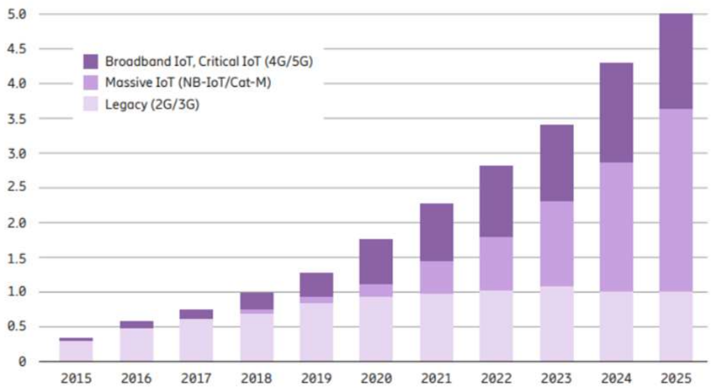
Mobile broadband subscriptions account for 77 percent of all mobile subscriptions

A new phenomenon on the horizon… with implications also in the cellular sector

mobile Machine-to-Machine, Cellular IoT, Cellular Automotive IoT, etc… are now a reality!

Cellular IoT

Figure 16: Cellular IoT connections by segment and technology (billion)



[1] Cat-M includes both Cat-M1 and Cat-M2. Only Cat-M1 is being supported today
[2] GSA, Oct 2019

Source: Ericsson Mobility Report

When did everything start?

- Free-space propagation has been used for nearly 100 years for telecommunications
- The first (rudimentary) systems of non-diffusive telecommunication with mobile means appear during the Second World War
- The first cell phone systems date back to the 1960s, but they are expensive, impractical, with low quality and low reliability

When did everything start?

1971

The world first successful commercial network was launched. The system relied on cars, began as half-duplex but soon evolved and had over than 35.000 subscribers by 1986.

1960

In 1960 the world first automated mobile telephone was introduced in Sweden. The system allowed automatic connection from a handset mounted in a car, but it required an operator for call forward. It was known as Mobile Telefone system A (MTA)

How it evolved over time?

Japanese operator NTT in 1979 built its own network. Five years later it was the first **1G** network to cover the entire country

1973

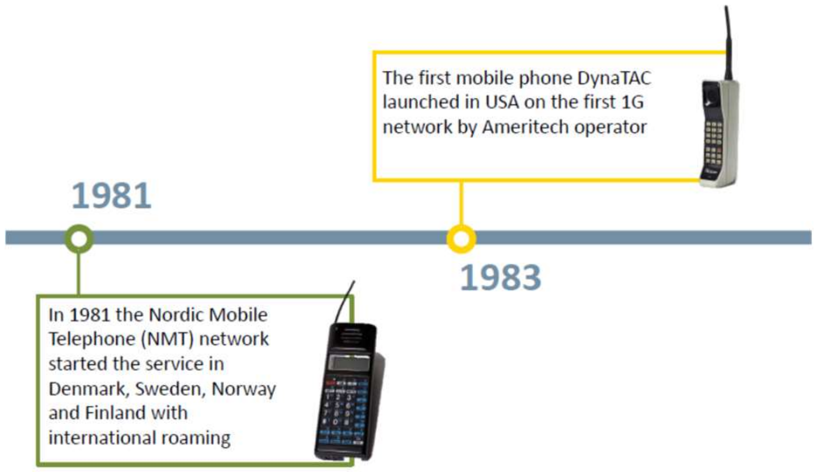
1979

The first call on a mobile phone made by Martin Cooper . The invention was sold for $ 3.995 and had a weight of approximately 1 kg (that's why it was called "the brick")

How it evolved over time?

- In the early 1980s, the first cellular networks in the "modern" sense of the term were installed (1983 Chicago)
  - "specialized" networks (e.g. private and owned by an organization)
  - quite expensive
  - low capacity and versatility
- In the second half of the 1980s, "advanced" analog networks (AMPS, NMT, TACS) were installed with immediate and enormous commercial success (1G)

How it evolved over time?



How it evolved over time?

The first generation (1G)

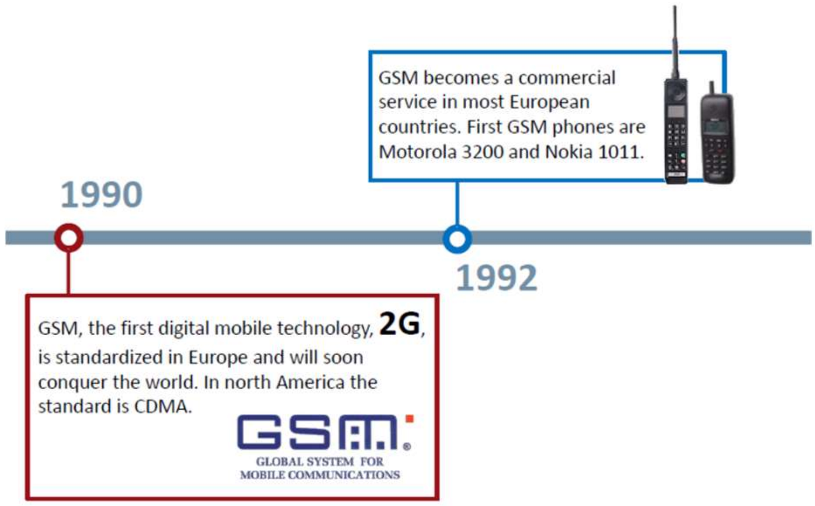
- AMPS: Advanced Mobile Phone Service
  - standard U.S.A. (EIA-553); bandwidth around 800 MHz
  - diffusion: Americas, Eastern Countries
- TACS: Total Access Communications System
  - standard developed in United Kingdom; bandwidth around 900 MHz, it is an adaptation of the AMPS standard
  - diffusion: Europe (Italy as well)
- NMT: Northern Mobile Telephone System
  - standard from Scandinavia, independent from AMPS and TACS; bandwidth around 450 and 900 MHz;
  - diffusion: Northern Europe

How it evolved over time?

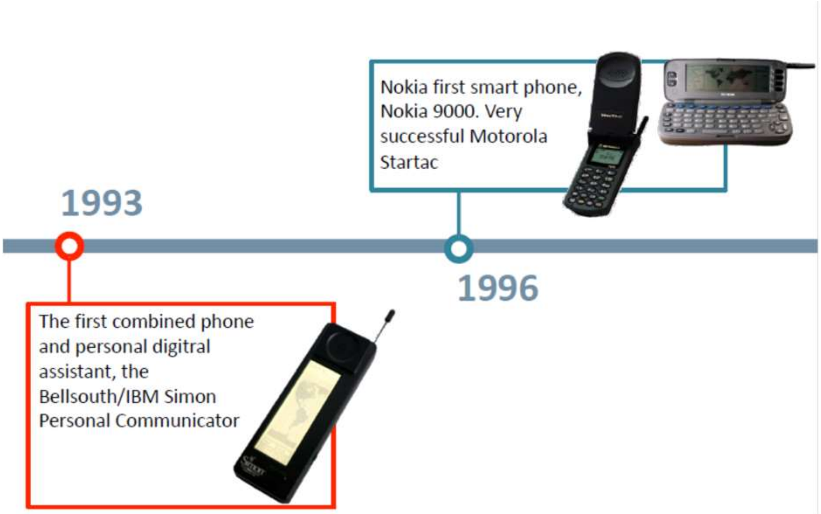
Towards the Second Generation

- Analog systems:
  - low capacity
  - poor quality of service
  - limited number of services
  - high equipment costs
  - interoperability problems between different systems
- Digital systems (2G-late 80s)
  - Integration of different services
  - Greater robustness to interference
  - Safety

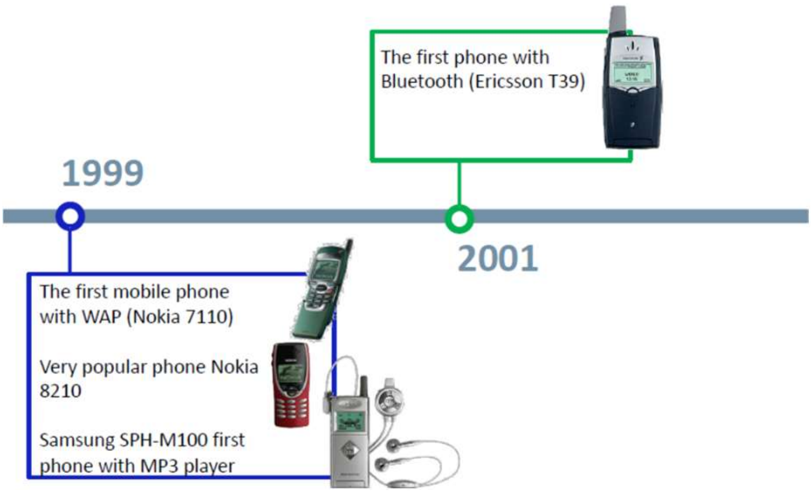
How it evolved over time?



How it evolved over time?



How it evolved over time?



How it evolved over time?

2001

NTT DOCOMO launches the world first **3G** service in October 2001

NTT Do Co Mo

2003

The first phone and PDA with OS and apps: Palmone Treo 600

How it evolved over time?

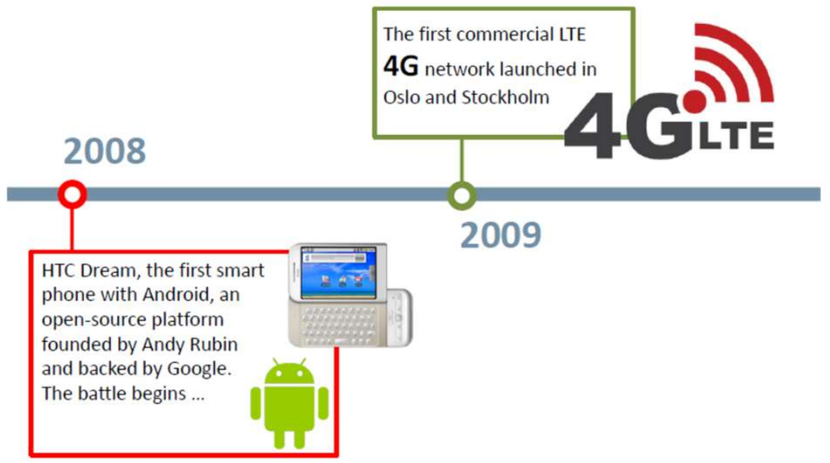
2004

Motorola Razor V3, one of the most popular phone among girls

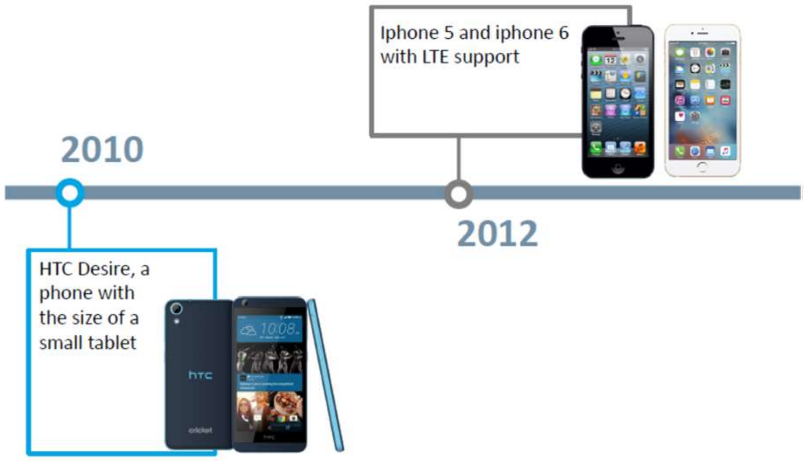
2007

The first iPhone launched by Apple and Steve Jobs

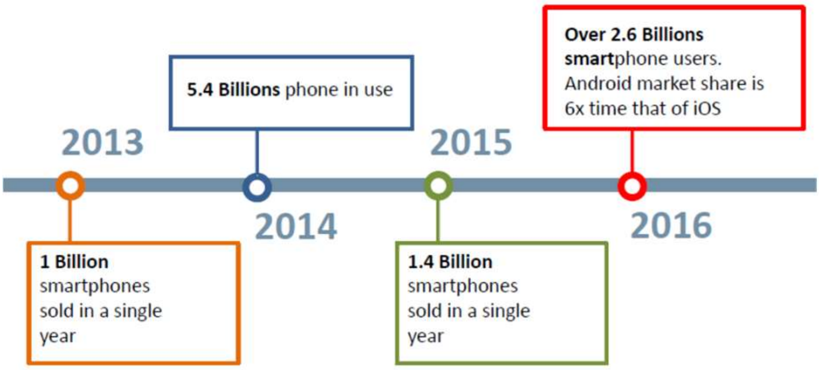
How it evolved over time?



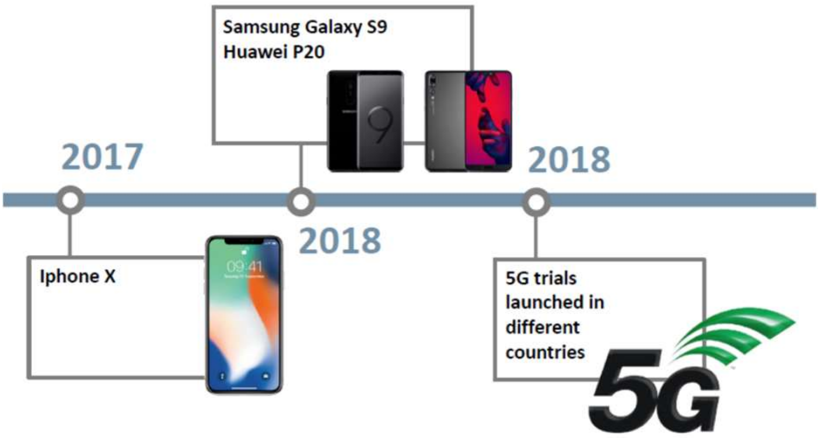
How it evolved over time?



How it evolved over time?



How it evolved over time?

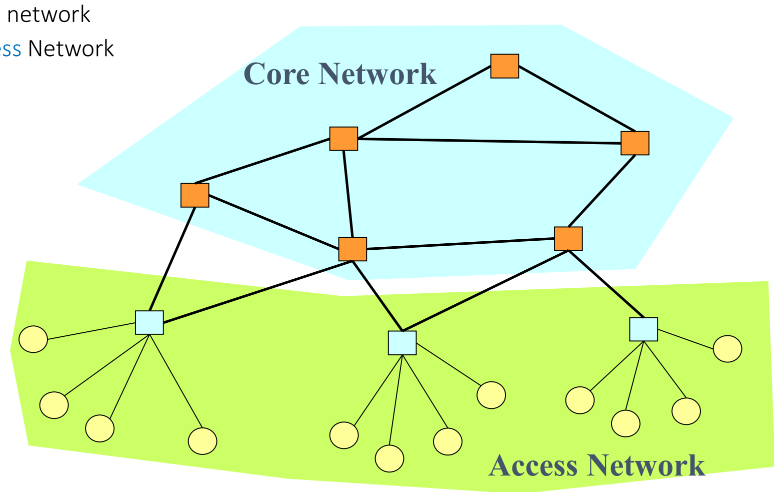


Mobile Radio Networks

❑ Basics Concepts

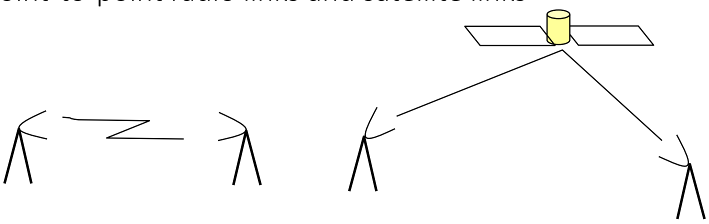
Wireless Networks vs. Radio Mobile Networks

- Any typical Network Architecture is composed of two segments:
  - Core network
  - Access Network



Wireless (access) networks

- Large modern transportation networks commonly make use of point-to-point radio links and satellite links

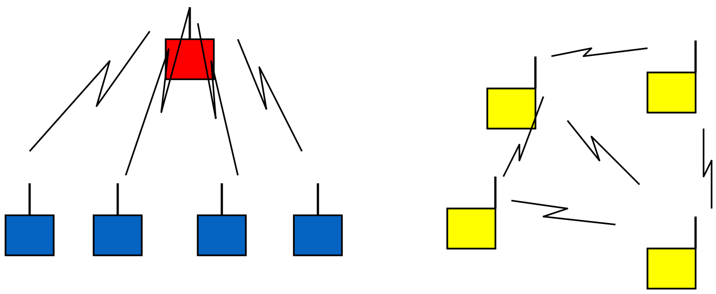


- Traditionally, however, "*wireless networks*" are defined only those in which the user's access is wireless
- Wireless networks can therefore also include wired transport network segments

Broadcast Channels

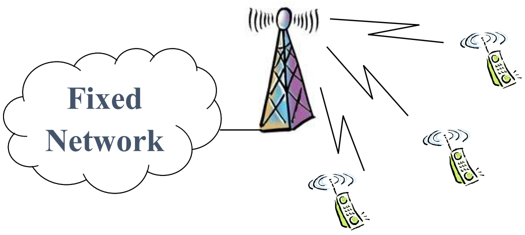
Central broadcast channels

Non-Central broadcast channels



Mobile networks

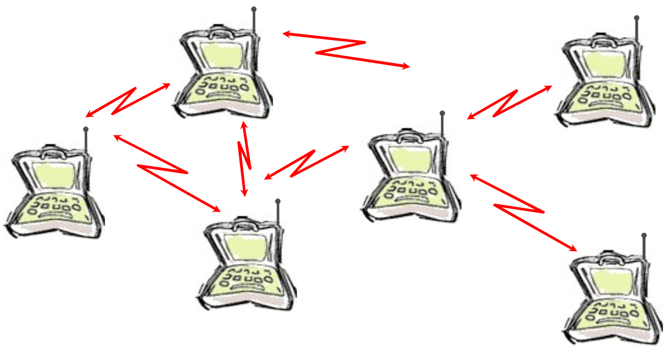
- Two types of wireless networks correspond to the two types of broadcast channels
    1) Fixed access point networks (mobile networks)



- Radio resources are shared because of the broadcast nature of the radio transmission medium
- In most (if not all) mobile services, the broadcast channel is centralized and UEs can communicate with the BS only and not directly between them
- Exceptions are D2D (device-to-device) services that are being investigated for 5G evolution

Ad-hoc wireless networks

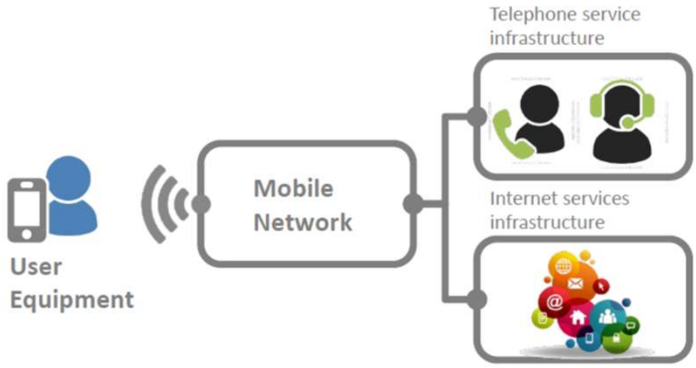
- Two types of wireless networks correspond to the two types of broadcast channels
    2) Ad-hoc wireless networks (Wireless LAN networks, MANETs, etc.)



- Also, mobile-mobile connections
- In multi-hop mode, mobile terminals have packet forwarding capabilities (ref. to "Wireless Devices and Networks" course)

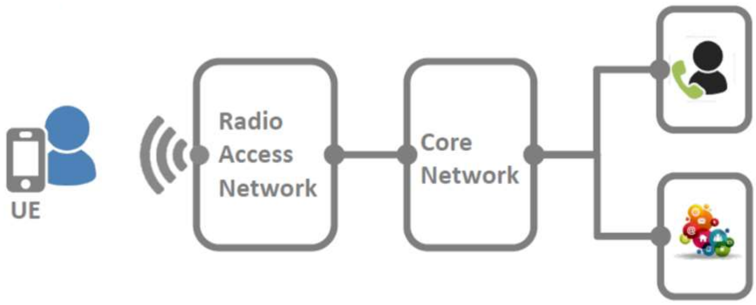
Mobile Networks

- Mobile networks allow radio user terminals, named UE (User Equipment), to connect to global network infrastructure and services, mainly telephone services and internet services



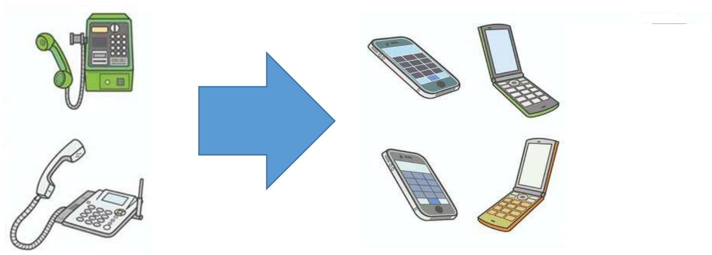
Radio Access Network and Core Network

- A mobile networks is divided in two main parts:
  - Radio Access Network (RAN), that handles the radio connectivity with users
  - Core Network (CN), that interconnects RAN to external services and infrastructures and provides connectivity and mobility management functions



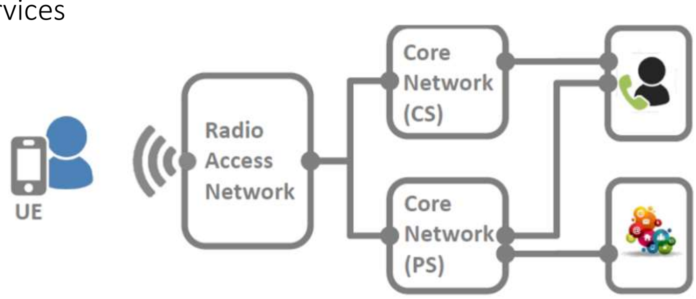
Services offered by a mobile network

- A mobile network usually offers two types of communication services
  - voice service
  - data service
- Historically, mobile networks were born for voice service and from this point of view they can simply be thought of as an evolution of fixed telephone networks



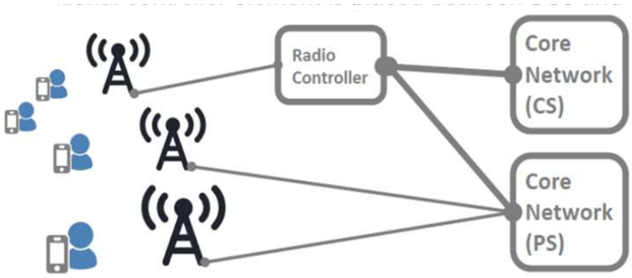
CS and PS Core Networks

- With 2G and 3G technologies, the core network that provide access to telephone service is based on circuit switching (CS), and a separate core network based on packet switching (PS) provides internet access
- With 4G and 5G the PS Core Network provides both voice and data services



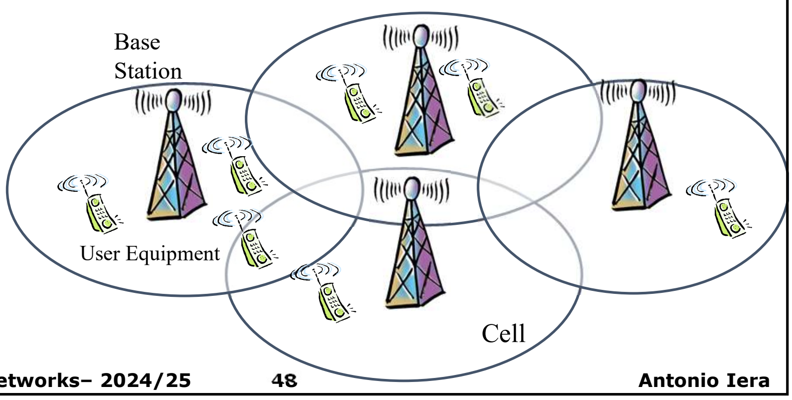
Base Stations

- The main architectural elements of RAN are Base Stations (BS) that connect to UEs through a radio interface
- For newest technologies, namely 4G and 5G, BSs directly connect to CN elements, while for 2G and 3G an additional controller element is placed between BSs and



Cellular concept

- BSs are deployed on the service area in order to provide connectivity to UEs in any position
- UEs connect to the most convenient BS (usually the nearest)
- The area where UEs connect to a specific BS is called cell



Requirements for mobile radio networks

- Capacity
  - ability to serve many users
- Coverage
  - ensure an acceptable signal level for a large area
- Quality
  - ensure communication quality parameters similar to those of fixed networks
- Flexibility
  - ability to access landline services
  - interoperability with “competing” systems

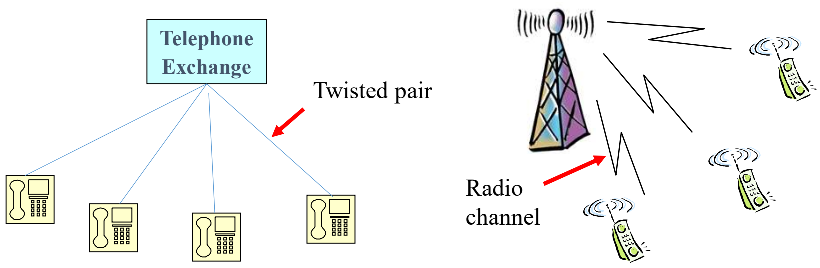
issues

- **Scarcity of radio resources (number and quality)**
- **User mobility management**
- **Extreme traffic variability (difficult to predict)**

Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

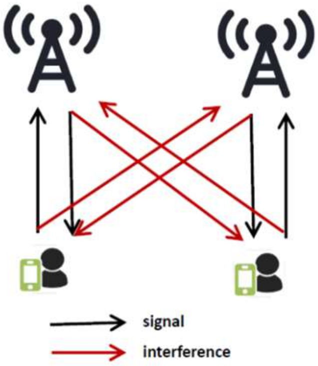
- Access Network
  - wireless channel
  - shared transmission medium, not dedicated



Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

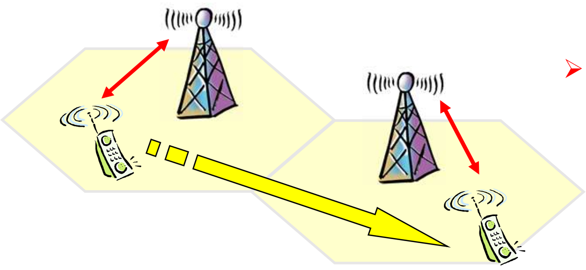
- Access Network
  - The radio resource is limited and can not be exclusively dedicated to a channel in a cell
  - The same radio resource is used in different cells, and this generate interference
  - Interference control is a critical problem with a trade off between channel quality and capacity
  - … see later on



Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

- User mobility
  - mobility in stand-by
  - mobility in conversation

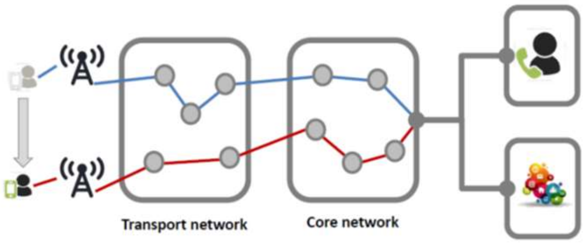


- Changing network access point

Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

  - User mobility
    - Since users can freely move in the service area, they can connect to different BSs in different moments
    - User mobility must be managed in the network since traffic must be routed according to user position



Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

  - Voice coding
    - to save radio resources the old 64 Kbit/s PCM is abandoned, and low speed encoders are used

- goodbye 4 KHz speech band!

Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

- **Let us now briefly analyze each of these aspects**
- **Those more related to network problems will then be resumed later**

- **wireless channel**
- **traffic theory**
- **shared medium**
- **mobility management**

Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

- **Let us now briefly analyze each of these aspects**
- **Those more related to network problems will then be resumed later**

- **wireless channel**
- **shared medium**

hints already given in «Wireless Dev. & Netw.» ... details will be provided during the exercise lessons of this course

Fixed telephone network vs. cellular network

- How is a cellular network that offers (mobile) phone service different from a fixed one?

- Let us now briefly analyze each of these aspects
- Those more related to network problems will then be resumed later

- **Basics of traffic theory will be given in excercize lessons**
- **Mobility management will be addressed for the various mobile network standards**

- **traffic theory**
- **mobility management**

The wireless channel

Wireless channel

- Compared to wired channel, the radio channel is a very "bad" transmission medium (the scenario changes dynamically)
- The signals that propagate in the air are subject to signal attenuation phenomena:
  - function of the distance between transmitter and receiver, due to propagation, constant (path loss)
  - due to propagation over multiple paths, fast (multipath fading or fast fading)
  - due to obstacles and changes in the configuration of the surrounding terrain (shadowing , slow fading)

Wireless channel: path loss

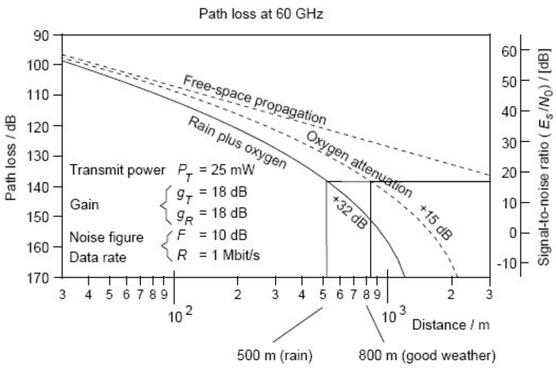
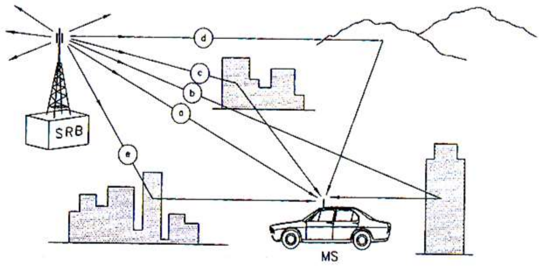


Figure 2.5: Attenuation due to weather conditions

- Furthermore, the propagation near the Earth's surface has different characteristics from those in free space ...

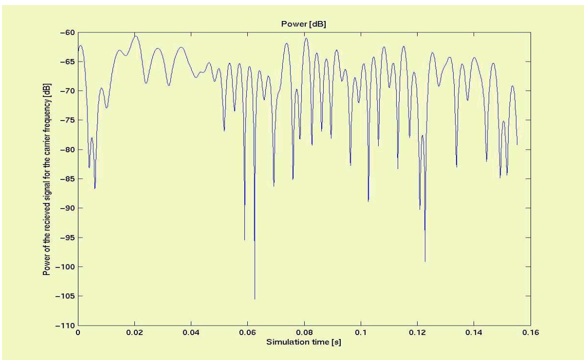
Wireless channel: multipath fading



- The replications of the signal coming from the different paths recombine at the receiver
- The result of recombination depends on:
  - number of replicas
  - relative phases
  - amplitudes
  - frequency

Wireless channel: multipath fading

- If the terminal moves it will cause the recombination characteristics to vary over time



- Fading holes tend to be spaced about the time it takes to travel half the wavelength

Wireless channel: reflection

- In propagation, the signal passes through or is reflected by obstacles that partially absorb the signal
- The reflected part is the result of a direct reflection and multiple reflections within the obstacle (e.g. a wall)

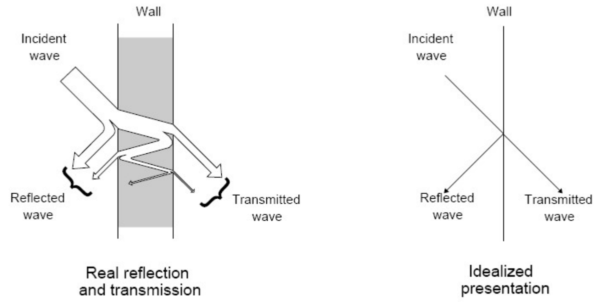


Figure 2.13: Reflection at a wall

- The sum of transmitted and reflected wave is less than the incident wave due to the dissipation due to multiple internal reflections

Slides of the «wWireless Devices and Networks» class (as a reminder)

Wireless channel: shadowing

- Obstacles in the path, so-called line-of-sight, between transmitter and receiver outdoor (buildings, mountains) or indoor (walls) prevent propagation on the direct route which is the shortest and usually the least interfered
- This generates additional attenuation which is usually called *shadowing*
- Usually, this attenuation is modeled by means of a log-normal variable x, therefore L = log (x) is a Gaussian variable with standard deviation σ which assumes values between 0 and 12 dB

Wireless channel: empirical models

- There are very sophisticated techniques for estimating the received power which are based on detailed knowledge of the characteristics of the area where the signal propagates (ray tracing techniques); however, these techniques are very expensive in terms of computational complexity
- Therefore, empirical models are often used that calculate distance attenuation with approximate formulas and add random attenuations for fading and shadowing

Wireless Channel: empirical models

- The best-known expression of distance attenuation is given by the formula of Okumura/Hata:

$$L_P = 69.55 + 26.16 \log f - 13.82 \log h_T - a(h_R) + \\ + (44.9 - 6.55 \log h_T) \log d \quad [\text{dB}]$$

- where
  - f : frequency in MHz (valid from 150 to 1500 MHz)
  - h_T : the height of the base station (in m)
  - h_R : the height of the mobile station (in m)
  - $a(h_R)$: correction factor depending on the area profile
  - d : distance (in km)
- In case of systems at 900 MHz, h_T = 30 m, $a(h_R) \approx 0$:

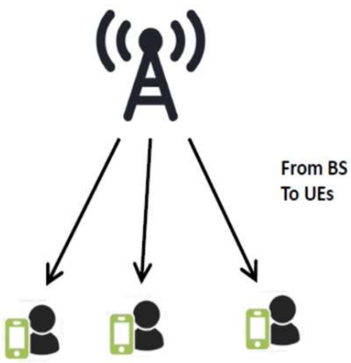
$$L_P = 126.42 + 35.22 \log d$$

where the propagation coefficientη=3.522

Shared Radio Access

Shared Radio Access: multiplexing

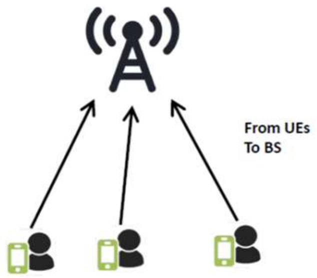
- The involved transmitting station is just one



Example: typical problem on the ***downlink*** direction (forward link) of cellular systems (from base station to user terminals)

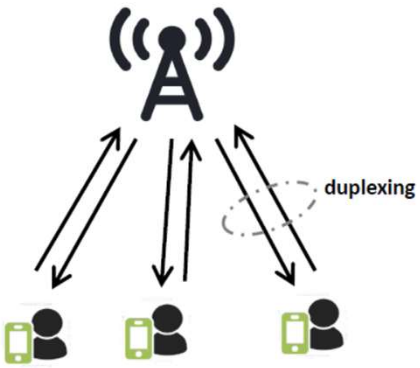
Shared Radio Access: multiple access

- Technique with which from a single broadcast channel others point-to-point channels can be obtained
- The transmitting stations can be multiple (<u>coordination problem</u>)



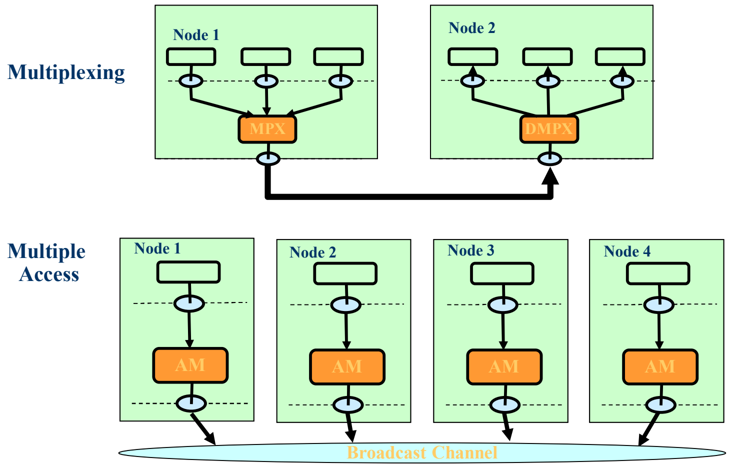
Example: typical problem on the *uplink* direction (reverse link) of cellular systems (from user terminals to the base station)

Shared Radio Access: multiple access



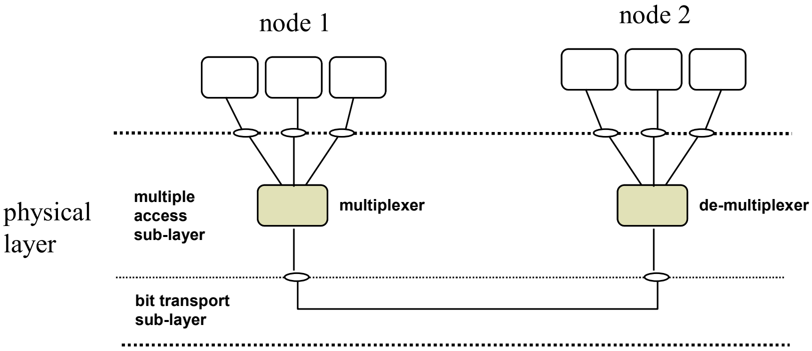
Note that a technique is also needed for the division between uplink and downlink channels (duplexing technique)

Shared Radio Access: Multiplexing/Multiple Access



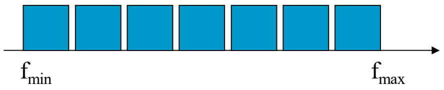
Physical multiplexing

- the distinction between flows occurs only on the basis of physical level parameters such as frequency, time, code, wavelength, etc.



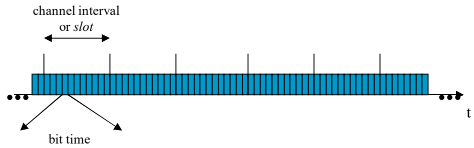
Different types of Multiplexing

- the overall band can be divided into sub-bands with which to associate a channel



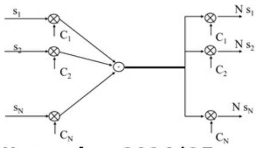
Frequency Division Multiplexing (FDM)

- given a numerical channel at C speed (bit / s), channel time intervals are constructed consisting of multiples of the bit time tb=1/C



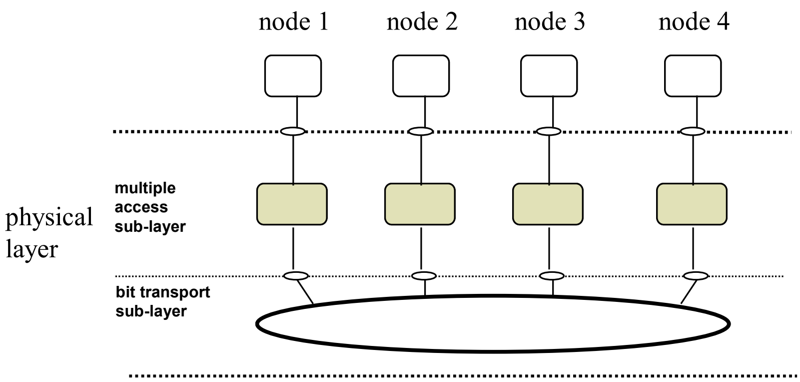
Time Division Multiplexing (TDM)

- mixing N bit streams after multiplying each of these with a code word Ci chosen from the N words of an orthogonal code

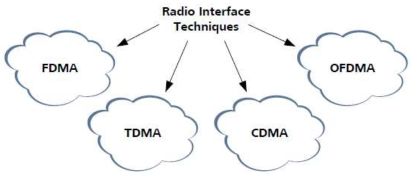


Code Division Multiplexing (CDM)

Multiple Access



Different types of Multiple Access



FDMA (Frequency Division Multiple Access)

- It is analogous to FDM, the need for station coordination does not create problems in the case of frequency division

TDMA (Time Division Multiple Access)

- is the analogue of TDM, coordination is needed to find a common time base for the stations (frame synchronism)

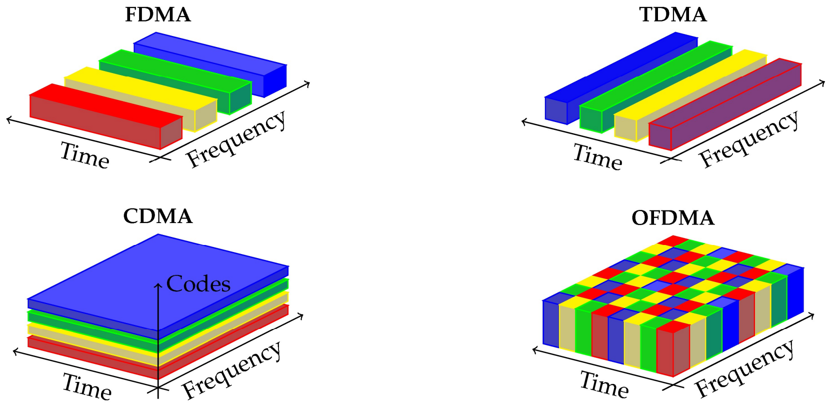
CDMA (Code Division Multiple Access)

- pseudo-random codes with low correlation are used for any time lag (not possible to maintain the orthogonality of the codes)

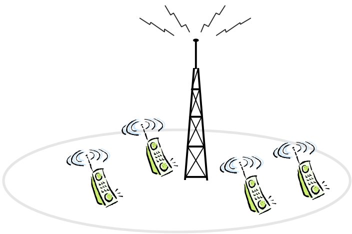
OFDMA (Orthogonal Frequency Division Multiple Access)

- bandwith split into different subcarriers orthogonal with each other, which, being orthogonal, is received independently.
- radio resources are two-dimensional (2D) regions in time (an integer number of OFDM symbols) and in frequency (a number of sub-carriers).

Multiple access: overview



Multiple Access in Radio Mobile Systems



- First Generation Systems: TACS (Europe) & AMPS (United States)
  - FDM/FDMA (downlink/uplink)
- Second Generation Systems:
  GSM (Europe)
  D-AMPS (United States)
  - Multi-carrier TDM/TDMA
- Third Gen. Systems:
  UMTS (worldwide)
  - CDM/CDMA
- Fourth Gen. Systems:
  LTE (worldwide)
  - OFDMA/SC-FDMA
- Fifth Gen. Systems:
  5G (worldwide)
  - Under investigation alternatives, such as Non-orthogonal Multiple Access (NOMA)