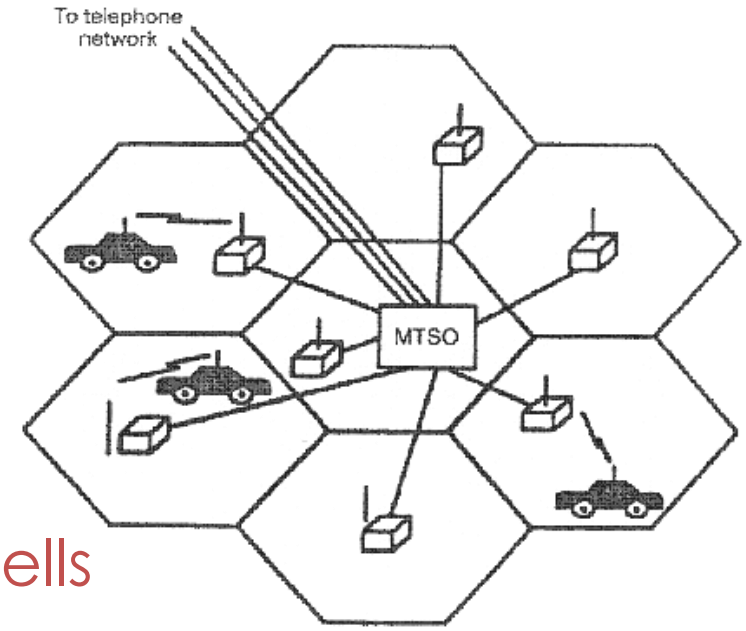
# Networking technologies and applications

May 4, 2015

# Cellular networks




- Elements of a cellular system:
  - Mobile station/node
  - Base station
  - Switching center (MTSO, MSC)
    - Mobile Telephone Switching Office
- The covered area divided into cells
  - Each cell has its own base station
  - Each cell has its own frequency domain
    - Neighboring cells on different frequencies
      - Avoiding interferences
    - Non-neighboring cells can use the same frequency
      - Cell-reuse

# The evolution of cellular networks

- **1G systems**
  - Analog communication, only voice transfer
    - AMPS – Advanced Mobile Phone System
      - USA, 800 MHz, 1983, Bell Labs
        - FDMA – each call on separate dedicated frequency
      - Obsolete, service stopped in February 2008
    - TACS – Total Access Communication System
      - UK, 900 MHz, 1985, Vodafone
      - Obsolete, Vodafone service stopped in 2001
- **2G systems**
  - Digital voice and data transfer
  - D-AMPS – Digital AMPS
    - Used in the USA and Canada
    - Designed to be compatible with AMPS
      - TDMA on the AMPS channels
    - Operated on 800 MHz (IS-54) and 1900 MHz (IS-136) as well
    - Service stopped in 2008

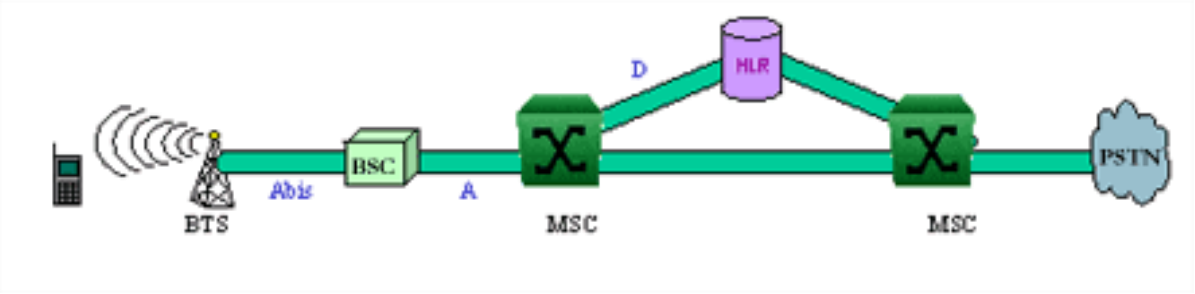
# The evolution of cellular networks

- **2G systems**
  - GSM – Global System for Mobile Communication
    - Originally a European solution, today a global system
      - SINTEF – Torleiv Maseng
      - 1991 – the first network

    - Today more than 400 GSM service providers, 3 billion subscribers in 212 countries
      - Introduced in the USA as well
    - On 850/900/1800/1900 MHz
      - 9,6 Kbps
    - Similarly to D-AMPS, it uses both FDM and TDM
      - The spectrum is divided in channels, the channels divided in time slots

# Elements of a GSM network

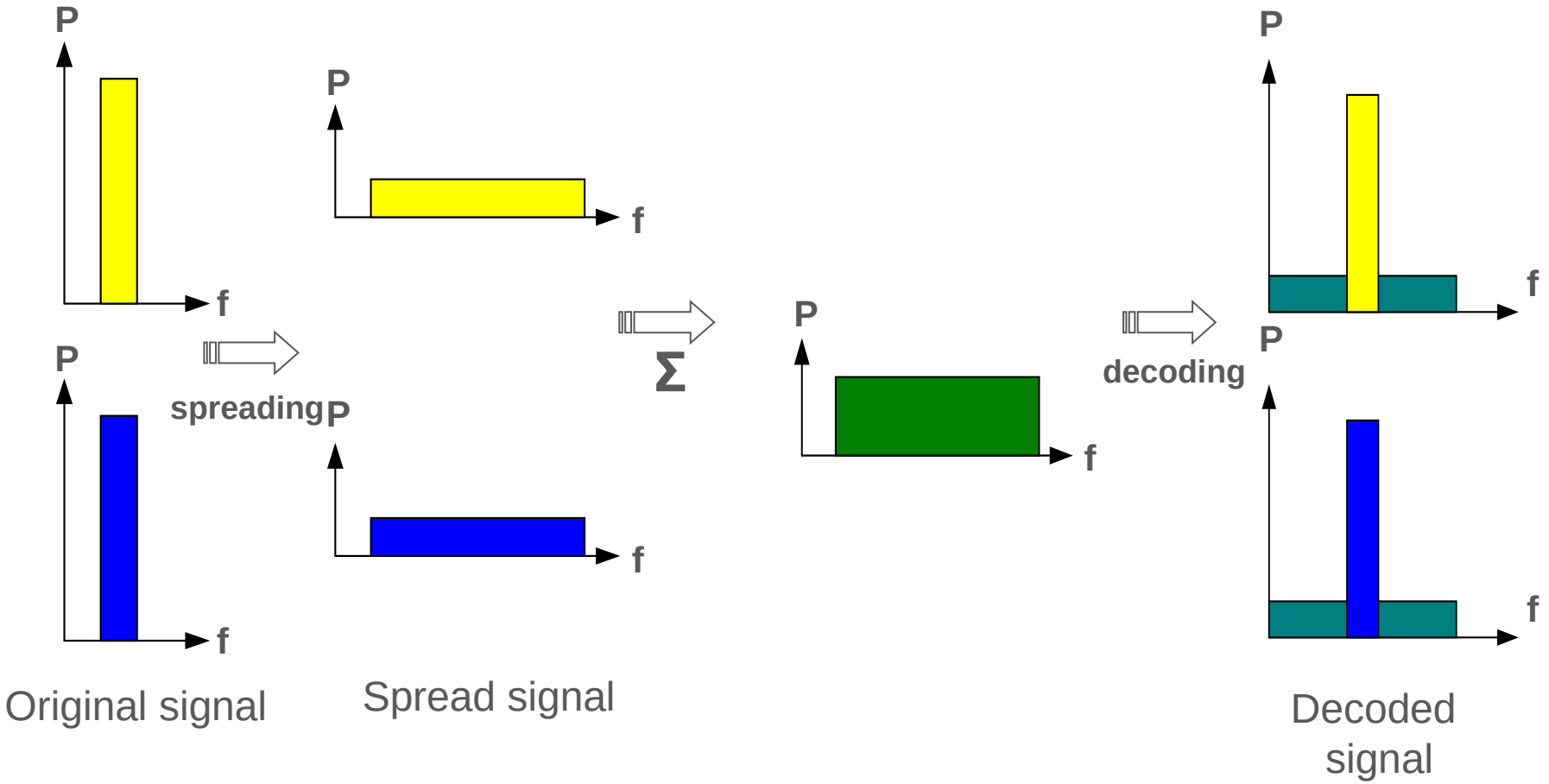
- BTS (Base Transceiver Station)
  - Maintains a radio connection to all the mobile stations inside its cell
- BSC (Base Station Controller)
  - Configures and controls the radio interface, handles the frequencies and the cell handoff (between two BTSs)
  - Can physically be placed inside the BTS
- MSC (Mobile Switching Center)
  - Connects the GSM network with the PSTN network
  - Handles the authentication, localization, cell handoff (between two BSCs), etc.
- HLR (Home Location Register)
  - Database about the users and their rights



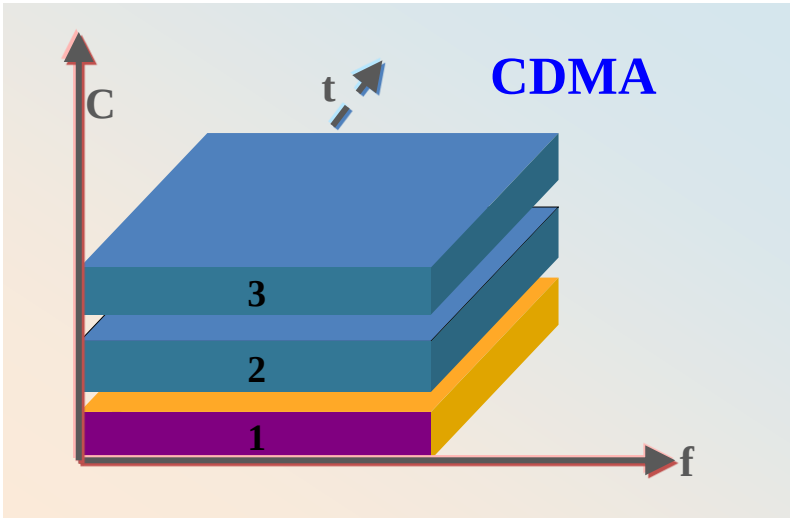
# The evolution of cellular networks

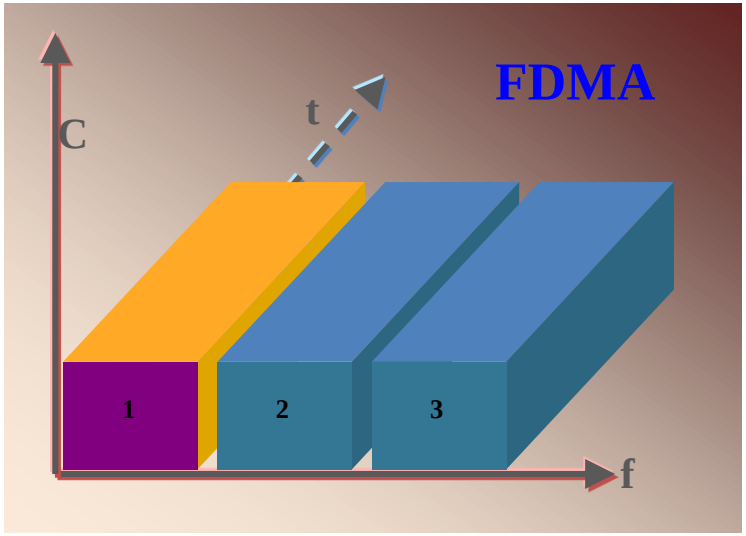
- **2G systems**
  - CDMAOne – Code Division Multiple Access
    - Described in the IS-95 standard, used in the USA as an alternative to D-AMPS
      - Sprint (CDMAOne) vs. AT&T Wireless (D-AMPS)
    - Each station transmits continuously over the entire frequency band
    - Parallel transmission separated using coding theory
      - The transmitter multiplies (XOR) the signal with a spreading code, and sends the result
      - The receiver multiplies the received signal once again, with the same code, reproducing the original signal
      - Each code is orthogonal
        - All the other signals transmitted in parallel are seen as noise

# CDMA basics

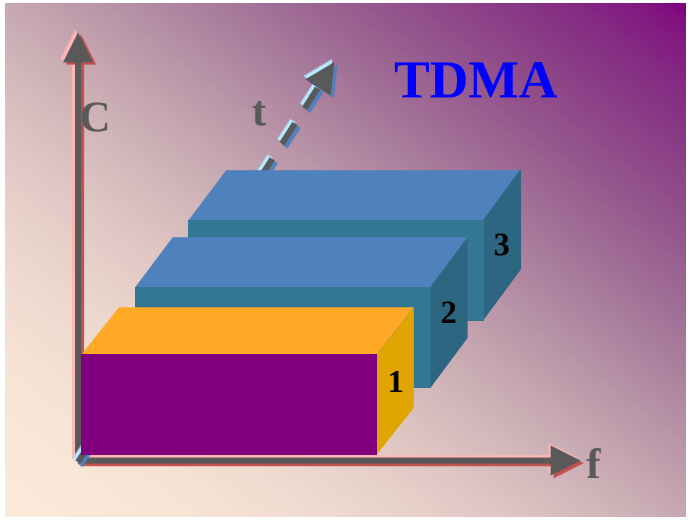

P
f
spreading
Σ
decoding
Original signal
Spread signal
Decoded signal

# Multiplexing solutions




**C** Code
**f** Frequency
**t** Time



# Duplexing vs. multiplexing

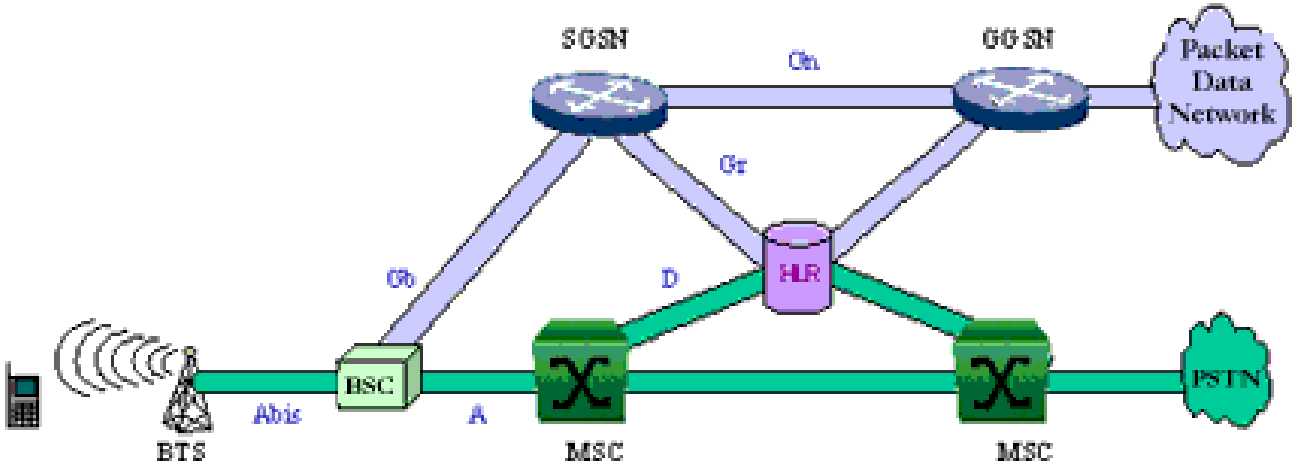
- **Multiplexing**
  - Sharing between the different users
    - Several separated user channels over the same physical resource
  - FDM – Frequency Division Multiplexing
    - The spectrum divided in frequency bands
    - Each user communicates over his own frequency
  - TDM – Time Division Multiplexing
    - Multiple users share the same channel
    - Users receive time slots inside the channel
  - CDM – Code Division Multiplexing
    - Each user uses continuously the entire channel
    - Traffic separated based on coding theory
- **Duplexing**
  - Separation of the downlink and uplink traffic
  - FDD – Frequency Division Duplexing
    - „Paired" frequencies, separate uplink and downlink channels
  - TDD – Time Division Duplexing
    - Unpaired frequencies, flexible separation of uplink and downlink traffic based on current conditions
- Several combinations of multiplexing and duplexing solutions can be used

# The evolution of cellular networks

- **2.5G systems**
  - Digital data transfer, higher speeds
    - Overlay infrastructure based on the 2G networks
  - GPRS – General Packet Radio System
    - Based on the GSM or the D-AMPS networks
    - More efficient channel utilization, lower prices
      - Traffic-based, not time-based charging
      - Packet-switched, not circuit-switched
    - 56 - 114 Kbps speeds
    - FDD + TDMA
      - The user receives a pair of uplink and downlink frequencies (channels)
      - Statistical multiplexing instead of traditional TDM
        - More efficient utilization, higher transfer speeds
      - Fixed length packets (that fit a GSM slot)
      - In the downlink direction, first-come first-served
      - In the uplink direction, similar to Reservation-Aloha
        - Improved Slotted-Aloha
        - The acquired timeslots are used by the same user, while it has data to send

# The GPRS network

- The BSC separates the packet-switched data traffic from the circuit-switched voice traffic
- Additional elements:
  - SGSN (Serving GPRS Suport Node)
    - Handles mobility, data encryption and compression
  - GGSN (Gateway GPRS Support Node)
    - Transforms the GPRS packets into IP packets
    - Edge router in the GPRS network
      - Directs the incoming IP packets to the appropriate SGSN
    - Firewall and NAT functions, authentication, accounting, distribution of IP addresses



# The evolution of cellular networks

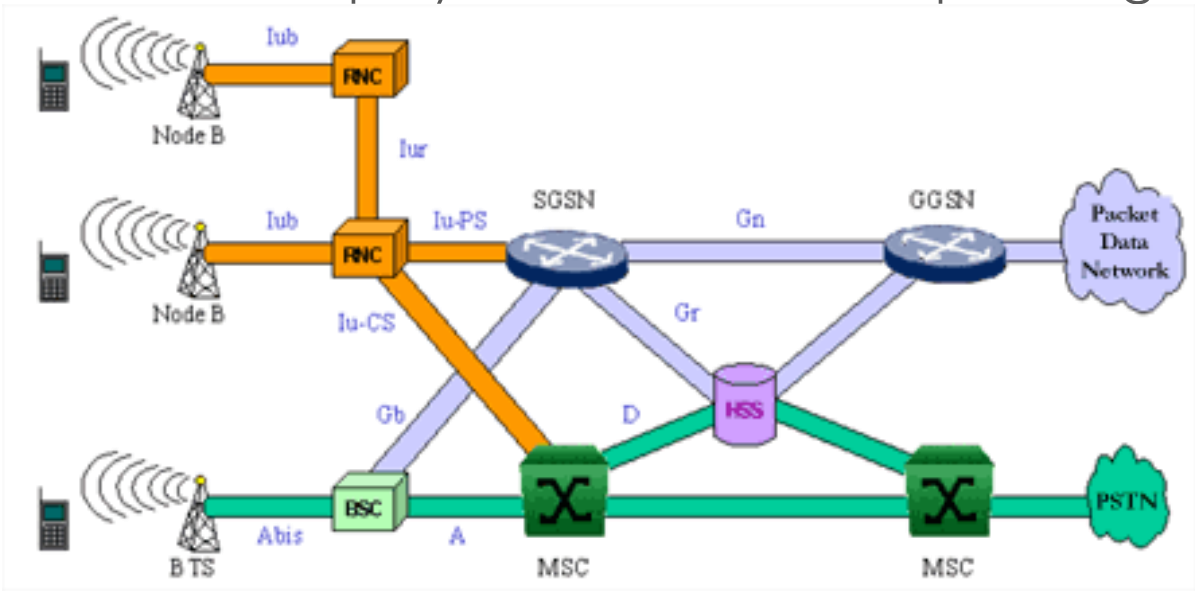
- **2.75G systems**
  - EDGE – Enhanced Data Rates for GSM Evolution
  - Introduced in the US in 2003
  - Operates on GSM frequencies (900/1800/1900 MHz)
    - Full GSM compatibility inside the network
    - The BTSs have to be replaced
  - Higher speed
    - Different modulation scheme and different speed, depending on channel quality
      - GSM/GPRS uses GMSK modulation
      - EDGE uses 8PSK in addition, for good quality channels
        - Theoretical max. speed 59,2 kbps / slot
        - Theoretically max. 8 slots – 473,6 kbps
    - Incremental redundancy
      - Instead of resending lost packets, more redundancy is used, if necessary
  - In December 2008, over 400 GSM/EDGE networks in 177 countries

# The evolution of cellular networks

- **3G systems**
  - Data traffic takes the leading role over voice, on mobile devices as well
    - Make phone calls, listen to music, watch movies and browse the web with high speed, over the same mobile phone
  - ITU project already in 1992
    - IMT-2000 – International Mobile Telecommunication
    - Planned to be deployed in year 2000, on 2000 Mhz, with a speed of 2 Mb/s
  - UMTS – Universal Mobile Telecommunication System
    - W-CDMA – Wideband CDMA
      - UMTS Forum, EU support
      - Combination of FDD and TDD
    - FOMA – NTT DoCoMo (2001)
      - The first W-CDMA system
      - At the beginning big user devices, short battery life
      - 40 million subscribers in 2007
  - CDMA2000
    - Qualcomm solution, expands the IS-95 (CDMAOne) standard
    - Might have been compatible with UMTS, but finally separate development, for political reasons (GSM compatibility)

# The UMTS network

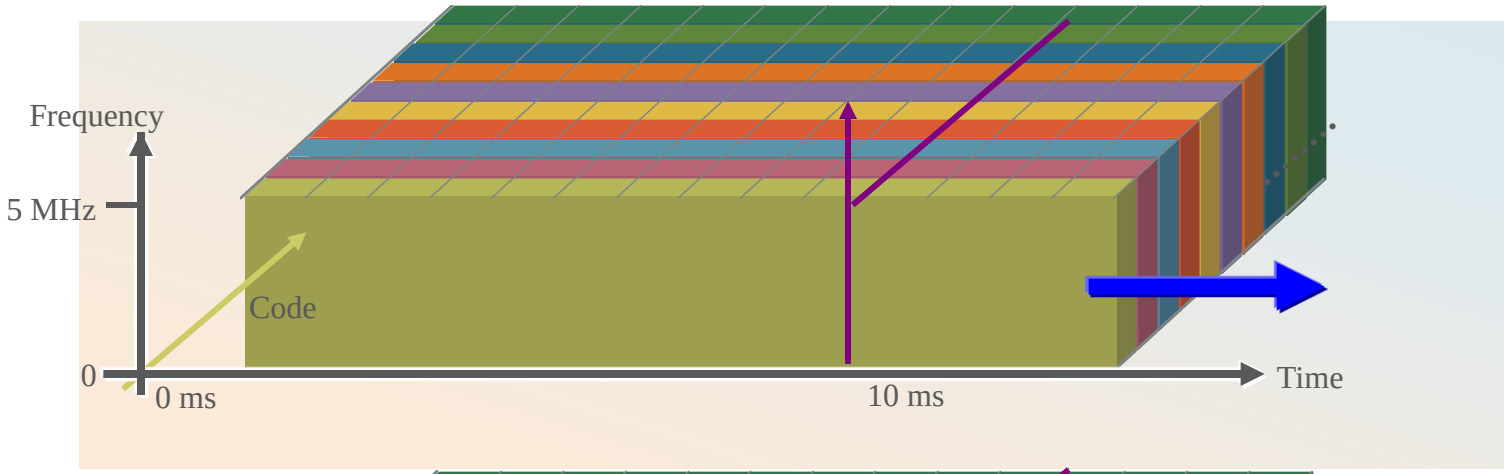
- Each UMTS cell is served by a Node B
  - Radio connection between the mobile devices and the UMTS network
- RNC (Radio Network Controller)
  - Verifies the utilization and reliability of the radio resources
- HSS (Home Subscriber Server)
  - Handles several database functions: HLR, DNS, etc..
- The UMTS network is compatible with the GSM networks
  - Permits incremental deployment, next to an operating GSM network



# W-CDMA access scheme (FDD)

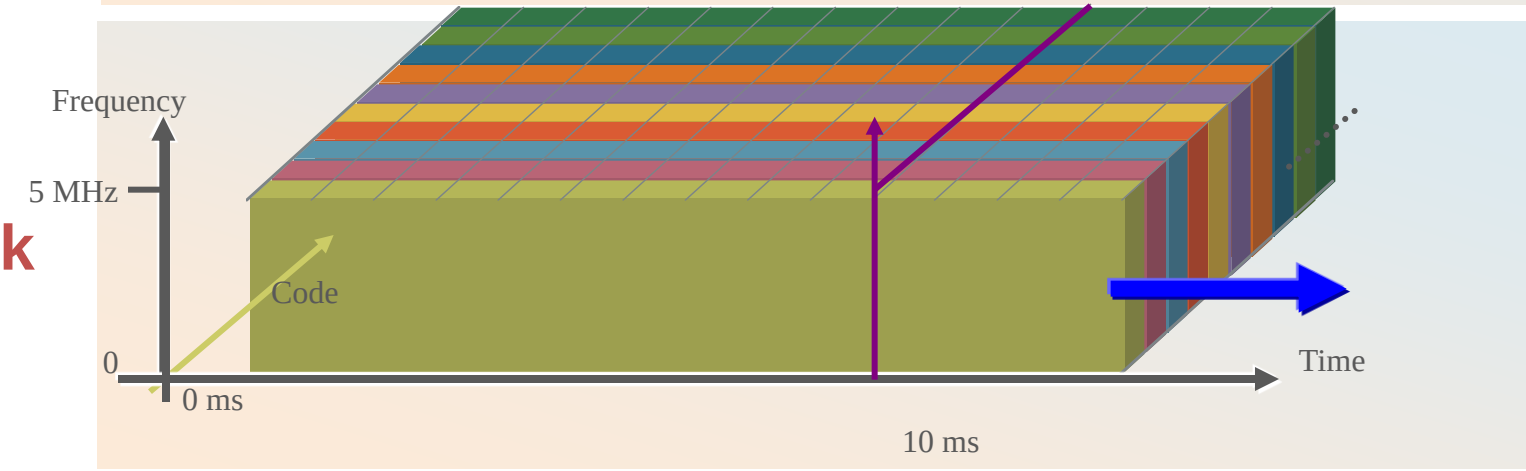
**Uplink**

**1920 - 1980 MHz**




**Downlink**

**2110 - 2170 MHz**

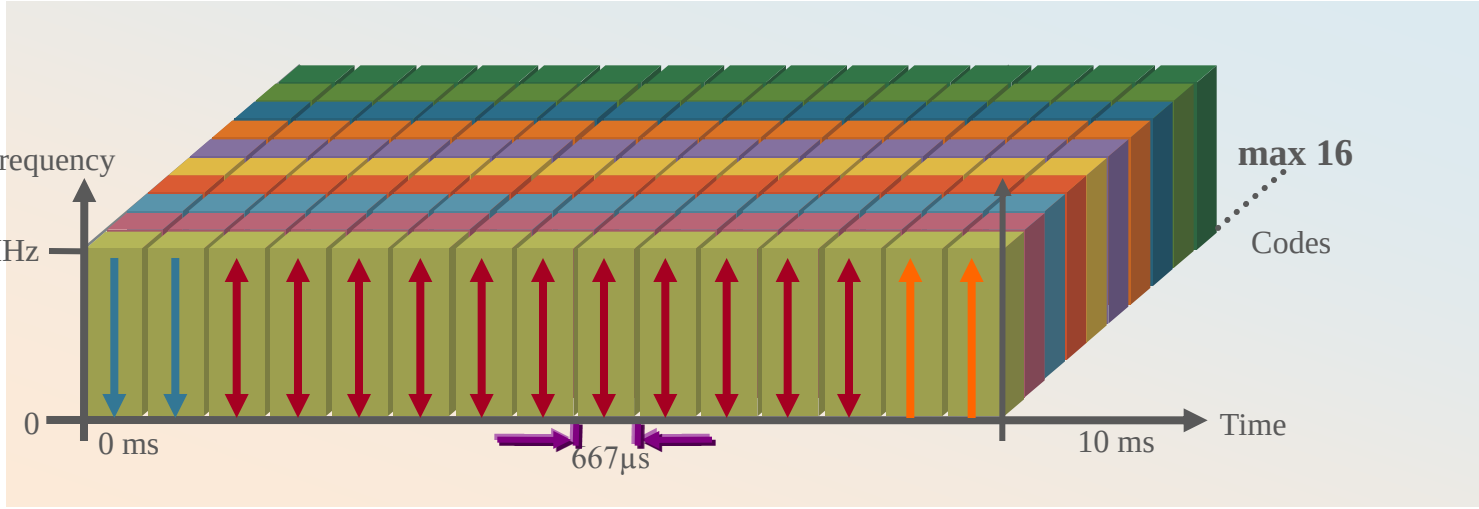


# TD-CDMA access scheme (TDD)

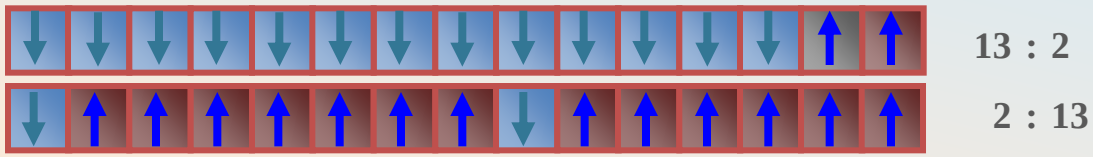
Uplink (↑)

Up-or Downlink (↑)(↓)

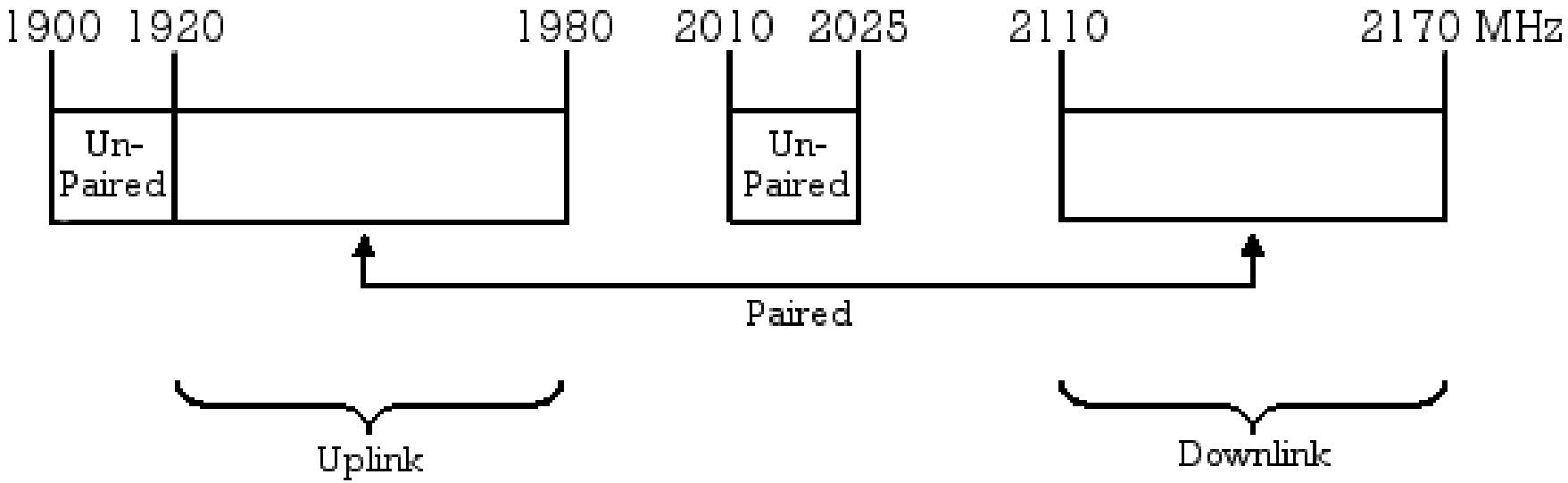
Downlink (↓)




Asymmetric



# UMTS spectrum licensing in Europe

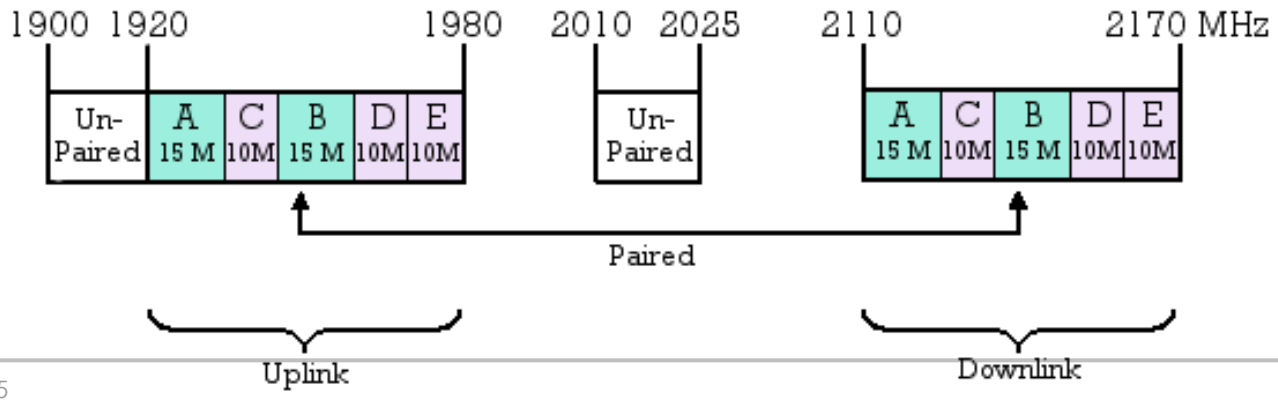


# 3G concession procedures

- Spectrum allocation among operators
- Concession procedures:
  - Auction
    - Who offers more for the spectrum
  - „Beauty contest"
    - Comparative bidding
    - The government asks for a detailed deployment and operating plan from the operators
      - How many new jobs will be created?
      - What kind of services will be available, when, where, for how much?
      - How will rural users be reached?
    - The offered money is of secondary importance
  - Mixed, hybrid solutions
- UMTS concession – UK
  - 5 licenses announced
  - Parallel auction for them
  - Dedicated band for newcomer operators
  - Total auction income: ~ 38,5 Billion EUR !!! (22,5 Billion GBP)
    - For comparison, the GDP of Hungary ~ 135 Billion EUR

# UMTS concession - UK

| Licence Name | Frequencies | Winner | Final Amount Bid |
|---|---|---|---|
| Licence A (reserved for a new entrant to the industry) | 2x15 MHz paired spectrum plus 5 MHz unpaired spectrum | Hutchison 3G | £4,384,700,000 |
| Licence B | 2x15 MHz paired spectrum | Vodafone | £5,964,000,000 |
| Licence C | 2x10 MHz paired spectrum plus 5 MHz unpaired spectrum | BT | £4,030,100,000 |
| Licence D | 2x10 MHz paired spectrum plus 5 MHz unpaired spectrum | One2One | £4,003,600,000 |
| Licence E | 2x10 MHz paired spectrum plus 5 MHz unpaired spectrum | Orange | £4,095,000,000 |



# UMTS concession

- Germany
  - 6 licenses announced
  - Total auction income: ~ 51 Billion EUR !!!
  - Winners:
    - T-Mobile (DT)
    - Mannesmann Mobilfunk (Vodafone – D2)
    - Group 3G (Sonera + Telefonica)
    - E-Plus Hutchison (KPN + NTT + Hutchison)
    - Mobilcom Multimedia (Mobilcom + FT)
    - Viag Intercom (BT + Viag + Telenor)

- Italy
  - 5 licenses, 6 candidate operators
  - Total auction income14,6 Billion EUR (10 auction rounds)

# UMTS licensing

- „Scandinavian model" – Sweden, Finland
  - Beauty contest (analysis of financial, technical background)
  - No licensing fee (percentage paid based on amount of traffic)
  - Sweden – Telia „blunder"
    - Telia lost the contest, although in 70% a state-owned company!!
- Spain, Portugal
  - An adapted Scandinavian model, minimal licensing fee, yearly payments
- Hungary
  - All three mobile operators received a UMTS license
  - T-Mobile, Pannon, Vodafone
  - 52.5 Billion HUF

# Licensing fees

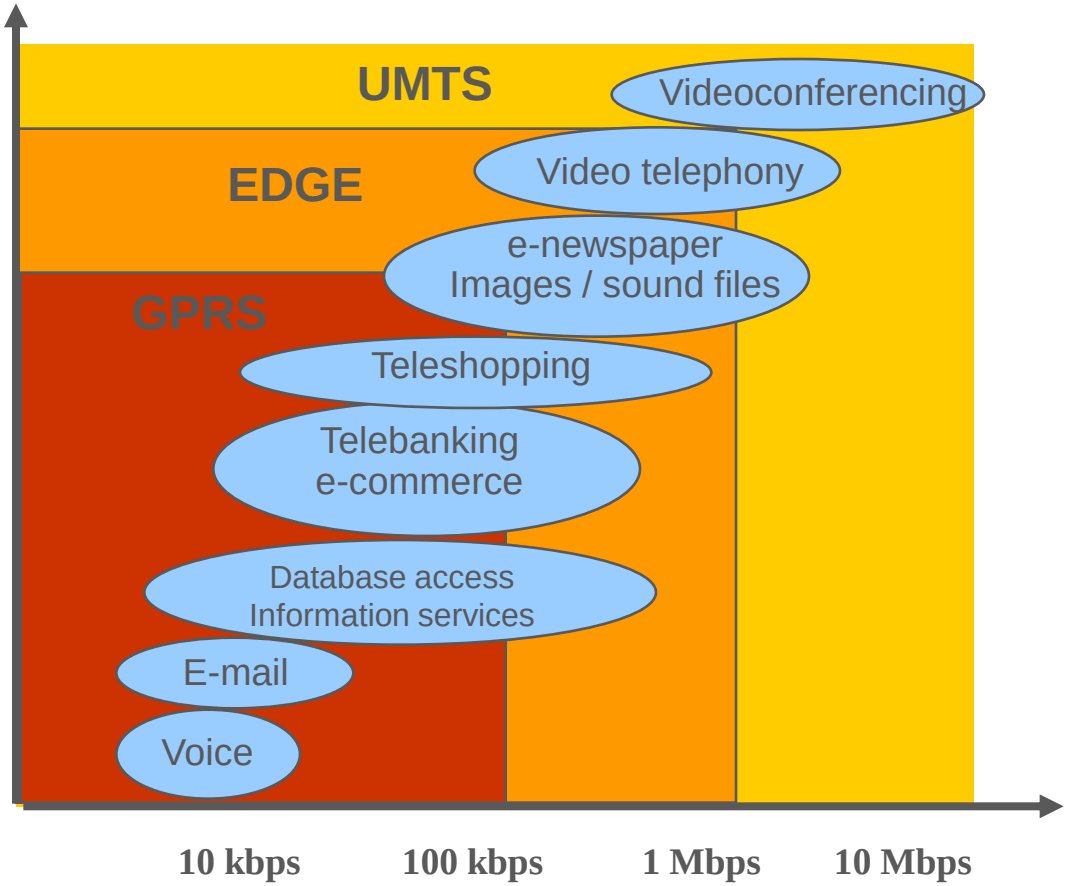
| | When | Type | Licenses | Income |
|---|---|---|---|---|
| England | 2000.04 | A | 5 | 38,500 Million EUR |
| Holland | 2000.07 | A | 5 | 2,700 Million EUR |
| Germany | 2000.08 | A | 6 | 51,000 Million EUR |
| Italy | 2000.10 | A | 5 | 14,600 Million EUR |
| Austria | 2000.11 | A | 6 | 830 Million EUR |
| Switzerland | 2000.12 | A | 4 | 130 Million EUR |
| France | 2001.05 | B | 2 | 1,200 Million EUR |
| Spain | 2000.03 | B | 4 | 520 Million EUR |
| Portugal | 2000.12 | B | 4 | 400 Million EUR |
| Belgium | 2001.03 | A | 3 | 450 Million EUR |
| Denmark | 2001. | A | 4 | 490 Million EUR |

*A – Auction*

*B – Beauty Contest*

# Supported services

**Supported services**



# 3.5G systems

- **HSDPA – High Speed Downlink Packet Access**
  - 1.8 – 14.4 Mbps downlink, 384 Kbps uplink
    - Efficient, adaptive modulation
      - QPSK for the noisy channels
      - 16QAM for the better quality channels
    - Incremental redundancy - Hybrid-Automatic Repeat-Request (HARQ)
      - Forward Error Correction + Error Detection bits (CRC)
      - Incorrectly received coded data blocks are stored at the receiver, not discarded
        - When the retransmitted block is received, the two are combined
      - Every retransmission contains different information than the previous one
        - Performs better than chase combining (retransmitting the same information), but at the cost of higher complexity

# 3.5G systems

- **HSDPA – High Speed Downlink Packet Access**
  - HARQ can be used in stop-and-wait mode or in selective repeat mode
    - In stop-and-wait the receiver sends ACK for each packet
      - Inefficient
    - Multiple stop-and-wait HARQ processes can be done in parallel
      - While one process is waiting for the ACK, other process can use the channel and send data
    - In selective repeat mode the sending continues (for a specified window size) even after a frame loss
      - An ACK is sent for each received frame, the sequence number of the earliest missed frame is added
      - When the sending window is emptied, the missed frame is resent

# 3.5G systems

- **HSDPA – High Speed Downlink Packet Access**
  - Fast packet scheduling
    - Mobile devices periodically report to the base station the downlink radio channel quality
      - 500 times per second
    - Based on this, the BS schedules whom should it send data to in the next 2 ms.
      - Sends more to those with good channel quality
  - A UMTS upgrade, in 109 countries, 250 networks
    - Usually 3.6 Mbps downlink speed
    - In Hungary started in May 2006
      - Pannon and Vodafone – 3,6 Mbps
      - T-Mobile - 7,2 Mbps

# 3.5G systems

- **HSUPA – High Speed Uplink Packet Access**
  - 5.76 Mbps max. uplink speed
  - QPSK – a better modulation scheme would put too much load on the battery of the mobile device
  - HARQ with incremental redundancy
  - Efficient scheduling
    - User devices ask permission for sending
    - The base station decides who can transmit and how much
      - Based on the sending buffer and the channel quality
  - Multi-Code sending
    - The same user equipment can use several codes in parallel
      - Maximum 4 codes
      - Higher speed for those who need it

- **EV-DO – Evolution Data Optimized**
  - An upgraded version of CDMA2000
  - 1,25 MHz large channels
  - Very similar to HSPA