# Mobile Networks: from 2G to 5G networks

Prof. Rami Langar
LIGM/UPEM
Rami.Langar@u-pem.fr
http://perso.u-pem.fr/~langar

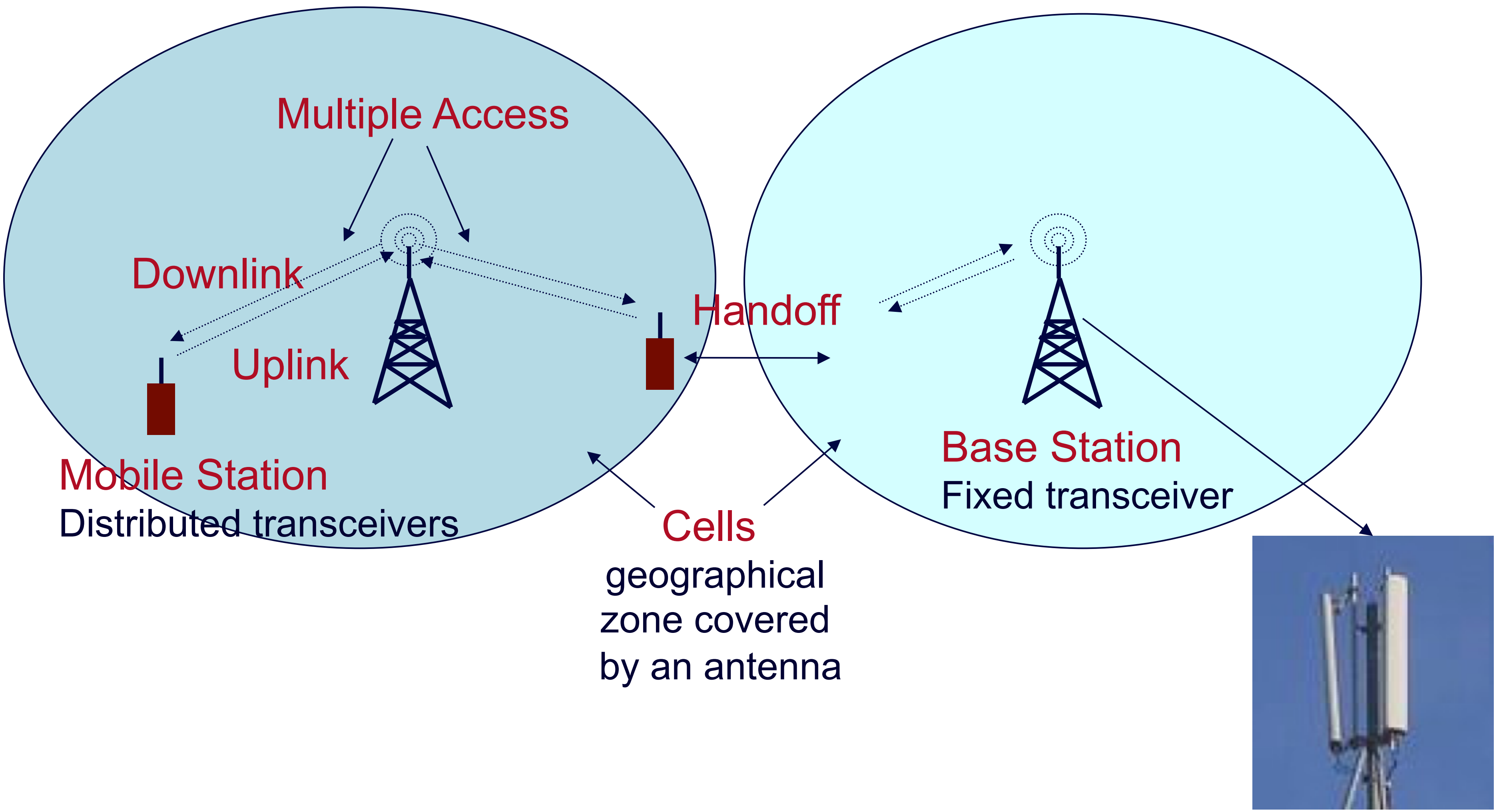
# History of mobile networks

- First generation
  - End of years 1970
  - Analog radio interface
  - E.g.: AMPS (Advanced Mobile Phone Service) in USA, Radiocom 2000 in France. TACS in England
- Second generation
  - Proposed around 1990
  - Digital radio interface
  - E.g.: GSM (Global System for Mobile Communications) for the 900 MHz band and DCS (Digital Communication System), which is the standard GSM in 1800 MHz band deployed in Europe and worldwide, IS-136, IS-95, GSM PCS 1900 in USA.
  - GPRS (General Packet Radio System): Inclusion of data networks.
- Third generation
  - Early 2000
  - Multimedia applications and Internet
  - E.g.: UMTS (Universal Mobile Telecommunication System)
  - Start of GPRS as enhancement to GSM for packet-oriented data transfer in 2001.
- 3G+, 4G and 5G
  - 3G+: High data rate
  - 4G: Multi-homing terminal
  - 5G: Cloud-based mobile networks

# GSM – Basis of current mobile systems

- GSM means *Global System for Mobile Communications*
- Introduction by the European telephone exchange offices
  - seamless roaming within Europe possible
- Today many providers all over the world use GSM (more than 210 countries in Asia, Africa, Europe, Australia, America)
- More than 747 million subscribers in more than 400 networks
- More than 10 billion SMS per month in France, > 360 billion worldwide (more than 10% of the sales of the operators)
- Uses the frequency ranges of 900, 1800, and 1900 MHz
- **Voice** and data connections with up to 9.6 KBit/s (enhancement: 14.4 KBit/s)
- Access control by chip-cards
- Cell structure for a complete coverage of regions (100 – 500 m Ø per cell in cities, up to 35 km on country-side)

# Basics: Structure



# Frequency reuse

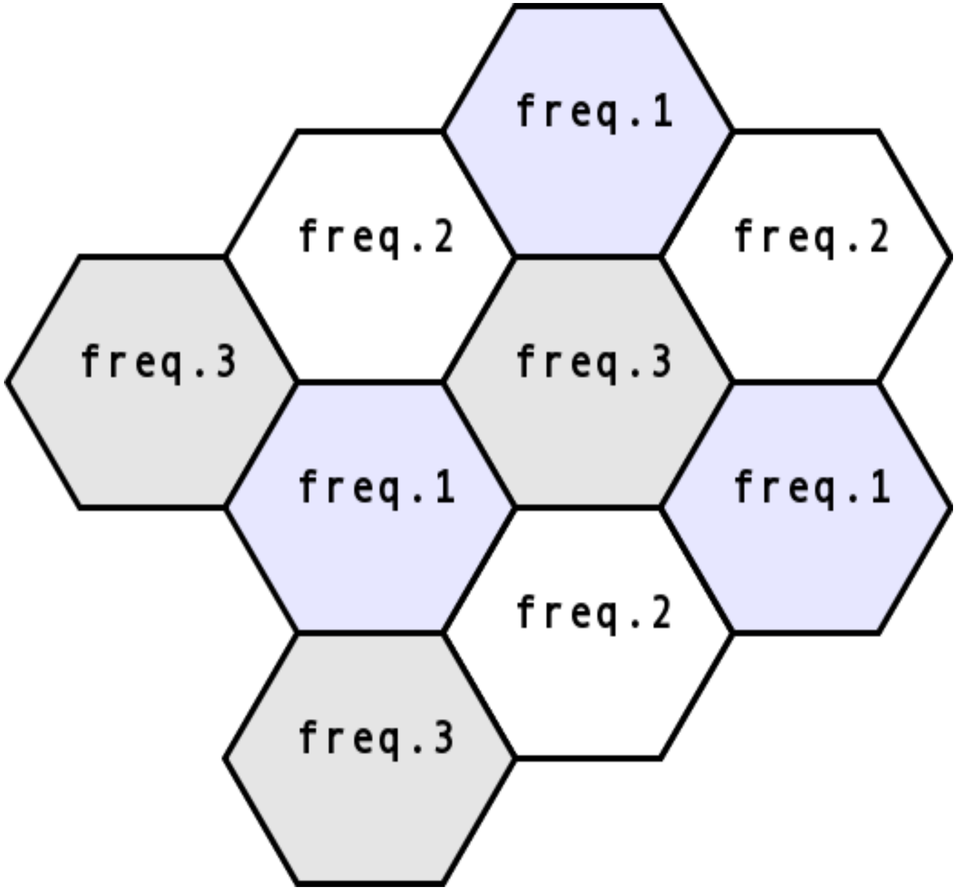
- Planning of cellular networks is a complex procedure
  - Cover the same area with a larger number of base stations (BS)
  - Partitioning of an area into radio cells idealized as hexagons, the hexagon is a rather good approximation of a circle
  - Size of a cell is determined by a maximum given transmission power (47dBm or 50 W) and a minimum receiver signal strength for a good voice quality.
  - Frequency channels could not be reused in neighboring cells because of interference
  - modelling: setup of clusters
  - Cluster contains: **k** cells, which use together the complete frequency range
  - **k** size of the cluster. Each cell $i$ ($1 \leq i \leq k$) in the cluster at least is assigned one frequency, but also several frequencies per cell are possible

# Cell planning

- Example of cluster size 3
- Generic formula

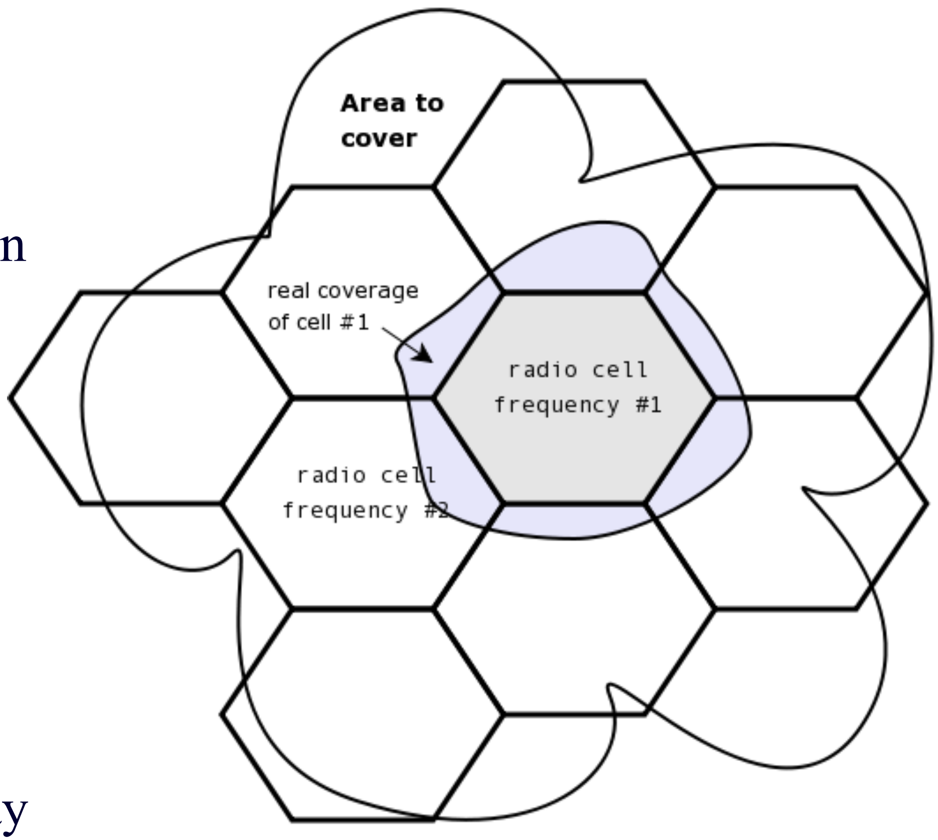
  $k = i^2 + i*j + j^2$

- Thus cluster sizes of 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, ... are possible
- With decreasing of cell size the capacity of the network increases
- But the interference as well as Handoff rate will increase (tradeoff)



# Clustering of areas

- More cells per cluster:
  - Less channels per cell
  - Lower system capacity
  - Less co-channel interference (co-channel cells have larger distance in between)
- Less cells per cluster:
  - More channels per cell
  - Higher system capacity
  - More co-channel interference (co-channel cells are nearby)
- Cell planning
  - Optimize the cluster size K in a way to maximize capacity and minimize interferences



# Cell Planning

# Cell Planning

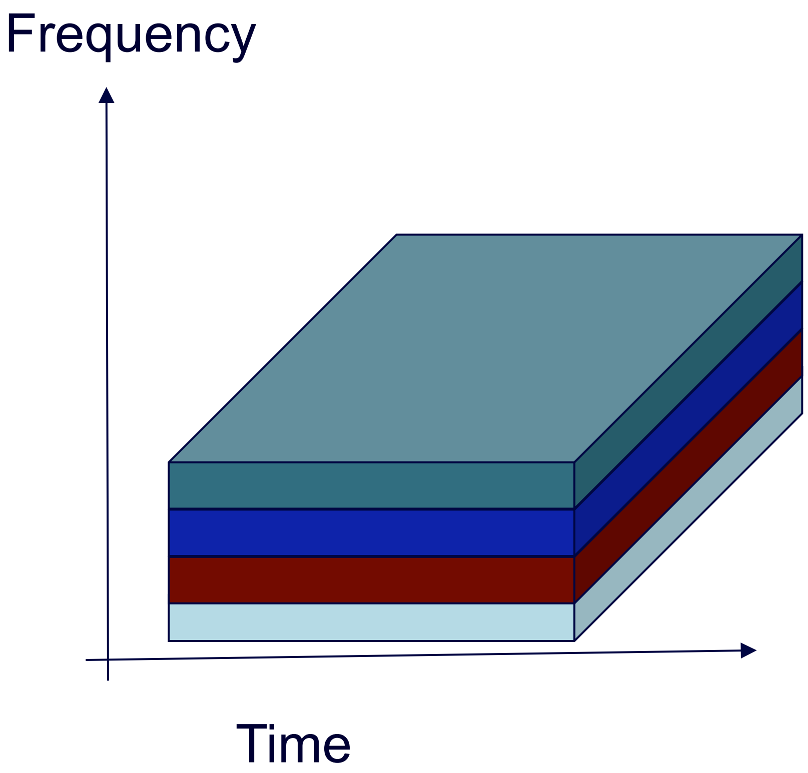
- General formula for frequency reuse distance:
  D = R * sqrt(3k)
- Valid for hexagonal geometry
  - D = reuse distance
  - R = cell radius
  - k = cluster size
  - q = D/R = frequency reuse factor
- For the example k=3, the reuse factor is 3, for k=12 is 6

# Basics: Multiple Access Methods

- Radio interface is responsible for the distribution of frequencies between users
- Need for a multiple access method to avoid collision
  - FDMA (Frequency Division Multiple Access) used in the first generation of mobile networks
  - TDMA (Time Division Multiple Access) used in GSM
  - CDMA (Code Division Multiple Access) used in IS-95 and 3G.
  - OFDMA (Orthogonal Frequency Division Multiple Access) for 4G and 5G.

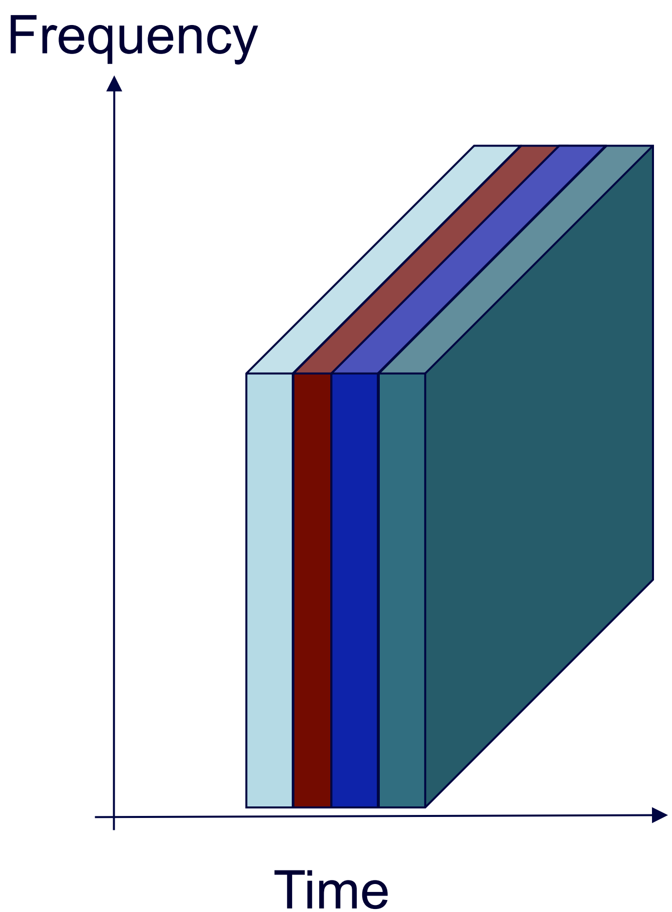
# FDMA

- The frequency band F is fragmented into n sub-bands to allow n simultaneous different users to be active.
- Every Mobile User is constituted by a transmitter, n receivers and n demodulators.
- Frequencies are attributed to users when they enters the cell.
- If one or several links are not used: waste of resources.



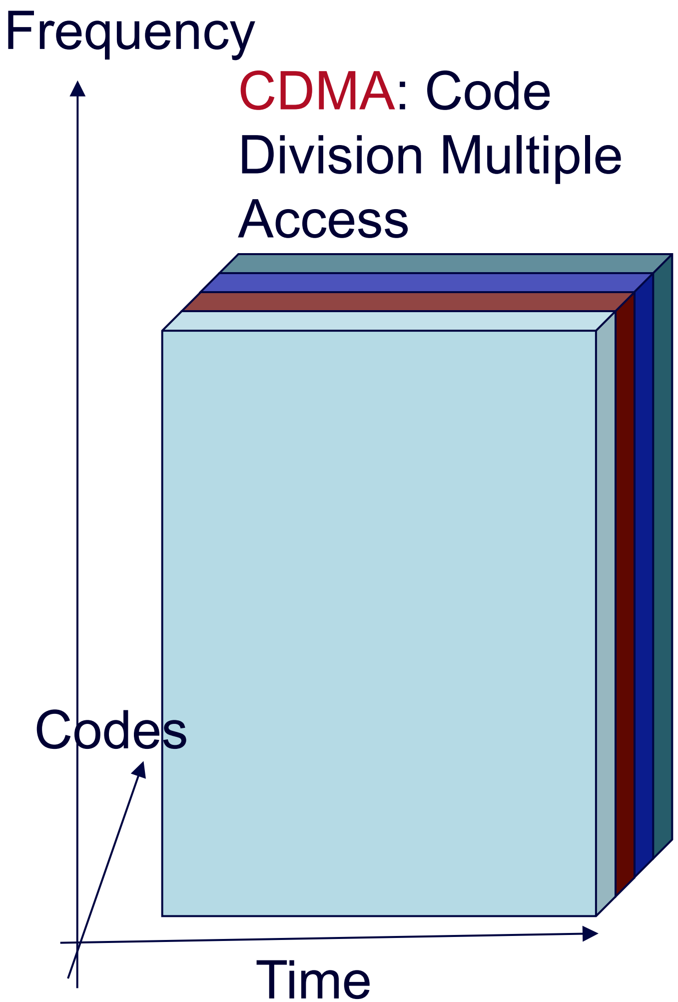
# TDMA

- Time is divided into slots. Each slot is associated to different users.
- Every user is equipped with one receiver/demodulator.
- A transmitted block within a slot contains a preamble for synchronization between the user and the BS and to avoid overlapping between two users' blocks.

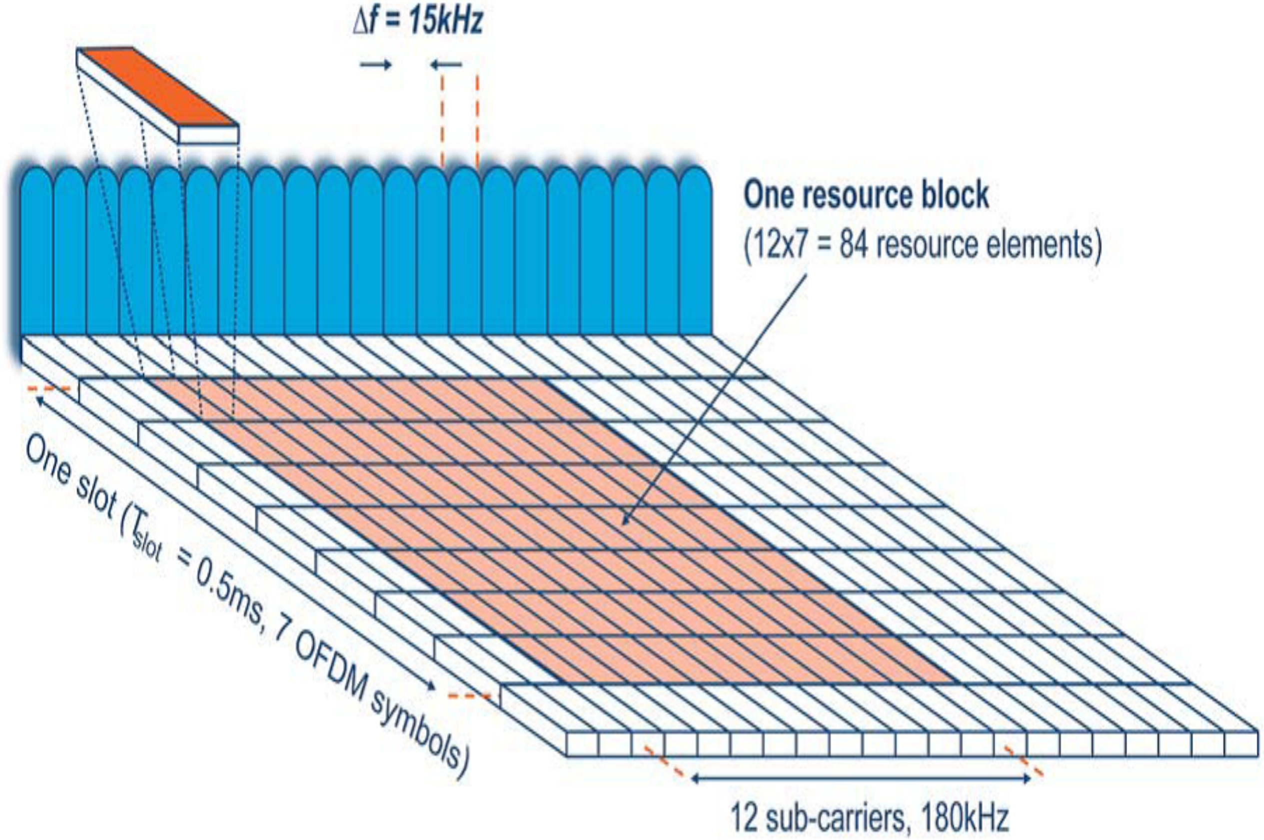


# CDMA

- Unique "code" assigned to each user; i.e., code set partitioning
- All users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
- Allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")



# OFDMA



Δf = 15kHz
One resource block
(12x7 = 84 resource elements)
One slot (T_slot = 0.5ms, 7 OFDM symbols)
12 sub-carriers, 180kHz

# Global System for Mobile communications (GSM)

- 900/1800 MHz band (US: 850/1900 MHz)
- For 900 MHz band uses 50 MHz in two 25 MHz bands for uo and down links :
  - Uplink: 890-915MHz
  - Downlink: 935-960 MHz
- 25 MHz bandwidth - 124 carrier frequency channels, spaced 200KHz apart
- GSM-1800 uses two 75 MHz bands with a maximum of 375 carriers at 200 kHz spacing.
- TDMA for 8 full rate speech channels per frequency channel.
- Circuit Switched Data with data rate of 9.6 kbps

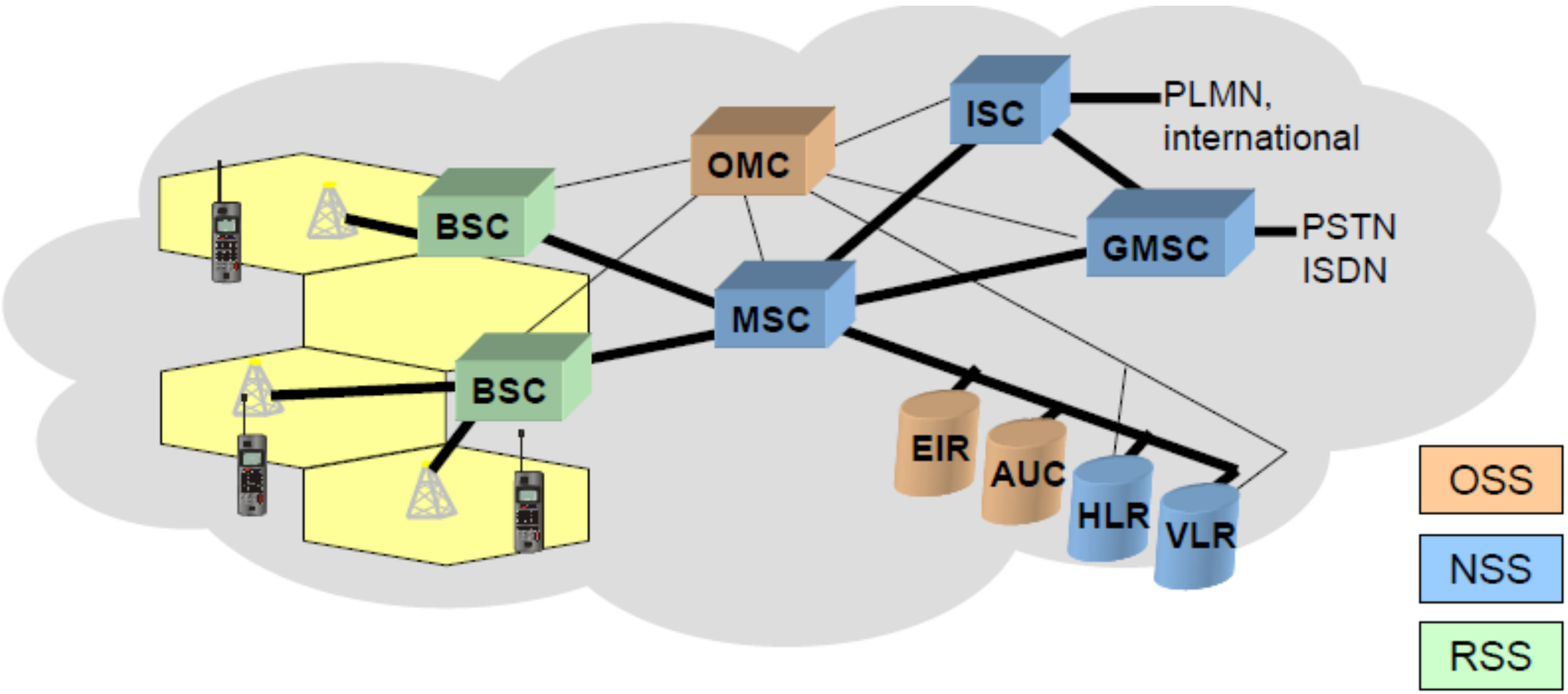
# Services in GSM

- Bearer services (BS)
  - Basic telecommunication services to transfer data between BSs.
  - Different data rates for voice and data up to 9.6 kbit/s.
  - signaling channel for connection control (used by teleservices)
- Teleservices (TS)
  - Mobile telephony, emergency calls (common number throughout Europe 112) mandatory for all service providers – free of charge, voice messaging
  - Short Message Service (SMS)
- Supplementary Services (SS)
  - Services in addition to the basic services
  - May differ between different service providers
  - Important services:
    - Identification: forwarding of caller number
    - Call hold
    - Call waiting
    - Call transfer to a third party

# Architecture of the GSM system

- The GSM system is a so-called PLMNs (Public Land Mobile Network). Several providers setup mobile networks following the GSM standard within each country
  - note: each provider has an own GSM network, but all are interconnected
- A GSM system consists of several components:
  - MS (mobile station)
  - BTS (base Transceiver station)
  - MSC (mobile switching center)
  - LRs (location register)
- Different subsystems are defined:
  - RSS (radio subsystem): covers all radio aspects
  - NSS (network and switching subsystem): call forwarding, handover, switching
  - OSS (operation subsystem): management of the network

# GSM Architecture




AUC: Authentication Center
BSC: Base Station Controller
EIR: Equipment Identity Register
GMSC: Gateway Mobile Switching Center
HLR: Home Location Register

ISC: International Switching Center
MSC: Mobile Switching Center
OMC: Operation and Maintenance Center
PLMN: Public Land Mobile Network
VLR: Visitor Location Register

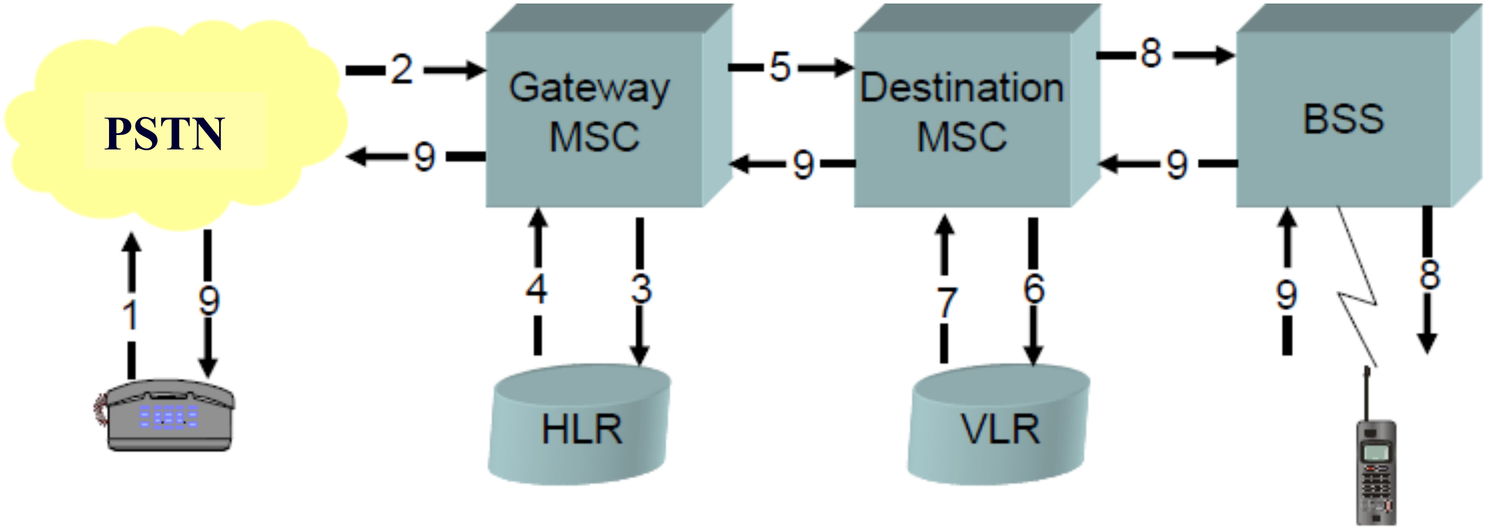
# Radio Subsystem (RSS)

- The radio subsystem is the cellular network up to the switching centers
- It comprises several components:
  - *Base Station Subsystem* (BSS):
    - *Base Transceiver Station* (BTS): radio components including sender, receiver, antenna. A BTS can serve one cell or, if directed antennas are used, several cells.
    - *Base Station Controller* (BSC): The BSC performs the switching between BTSs and the control of several (tens to hundreds) BTSs. It manages the network resources, signaling transmission, power control, handover control between BTSs.
    - BSS = BSC + Sum (BTS) + interconnection
  - Mobile stations (MS) are seen as mobile network components.

# Network and Switching Subsystem (NSS)

- The network subsystem is the main component of the public mobile network GSM. It interconnects the BSSs with other networks and performs switching, mobility management, and system control
- Components are:
  - *Mobile Services Switching Center* (MSC): controls all connections via a separated network to/from a mobile terminal within the domain of the MSC – several BSC can belong to a MSC
  - Databases :
    - *Home Location Register* (HLR): central master database containing user data, permanent and semi-permanent data of all subscribers assigned to the HLR, roaming restriction, information about permanent users' location (one provider can have several HLRs)
    - *Visitor Location Register* (VLR): local database for a subset of user data, including data about all user currently in the domain of the VLR.

# Connection Establishment

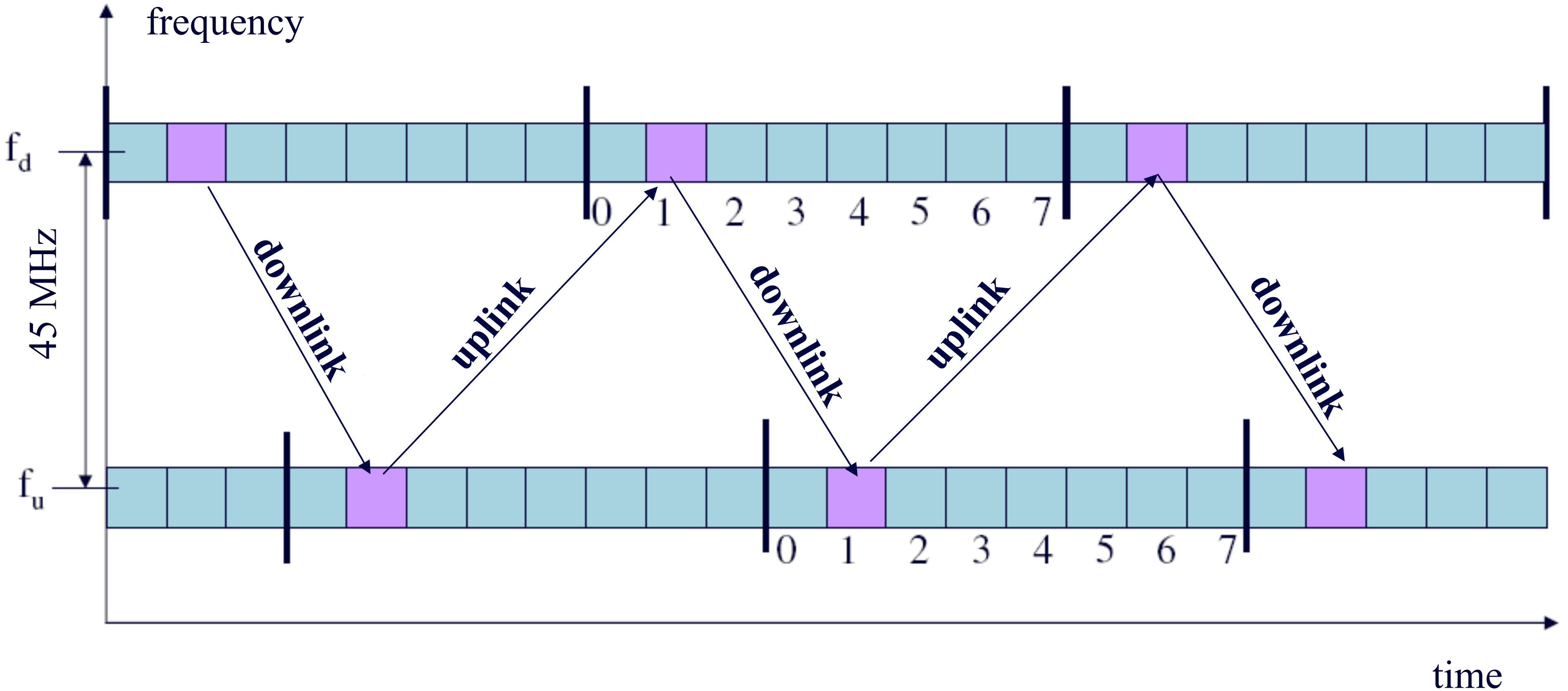



1 - Call for a mobile station
2 - PSTN forwards call to the GMSC connecting the GSM network
3 - GMSC uses HLR to request currently responsible MSC
4 - Response with switching information to the current subscriber location
5 - Forwarding of the call to the destination MSC
6 - MSC requests exact position of the subscriber in its VLR
7 - VLR checks service profile and availability of the MS and gives back the current BSS
8 - Paging of the mobile subscriber (broadcast in the whole BSS)
9 - MS answers, call can be established

# Physical channel

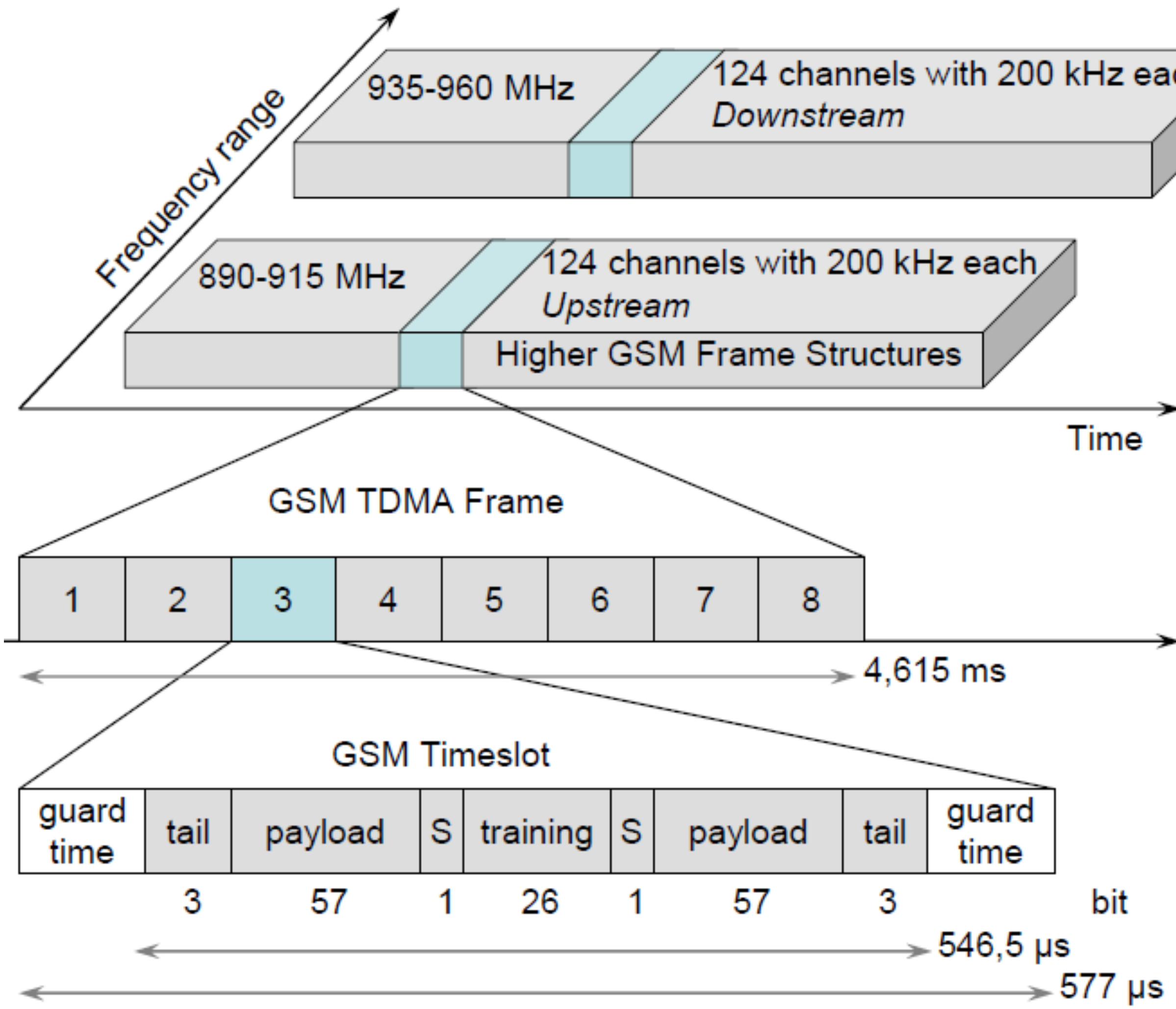
- After deducting 100 kHz as guard band at both ends of the spectrum, only 124 carriers are used.
- Radio frequency channel number N Є {1, 2, …, 124} is defined and corresponds to center frequency in MHz as follows for GSM-900
  - $f_{up} = 0.2\,N + 890$
  - $f_{down} = 0.2\,N + 935$
- For GSM-1800, N Є {512, 513, …, 855}
  - $f_{up} = 0.2\,N + 1607.8$
  - $f_{down} = 0.2\,N + 1702.8$

# Physical channel




- Each user uses one slot per TDMA frame (same number in uplink and downlink) with a shift of 3 time slots between sending and receiving time to avoid the need for duplex-enabled transceiver units.

# TDMA frames and Traffic bursts

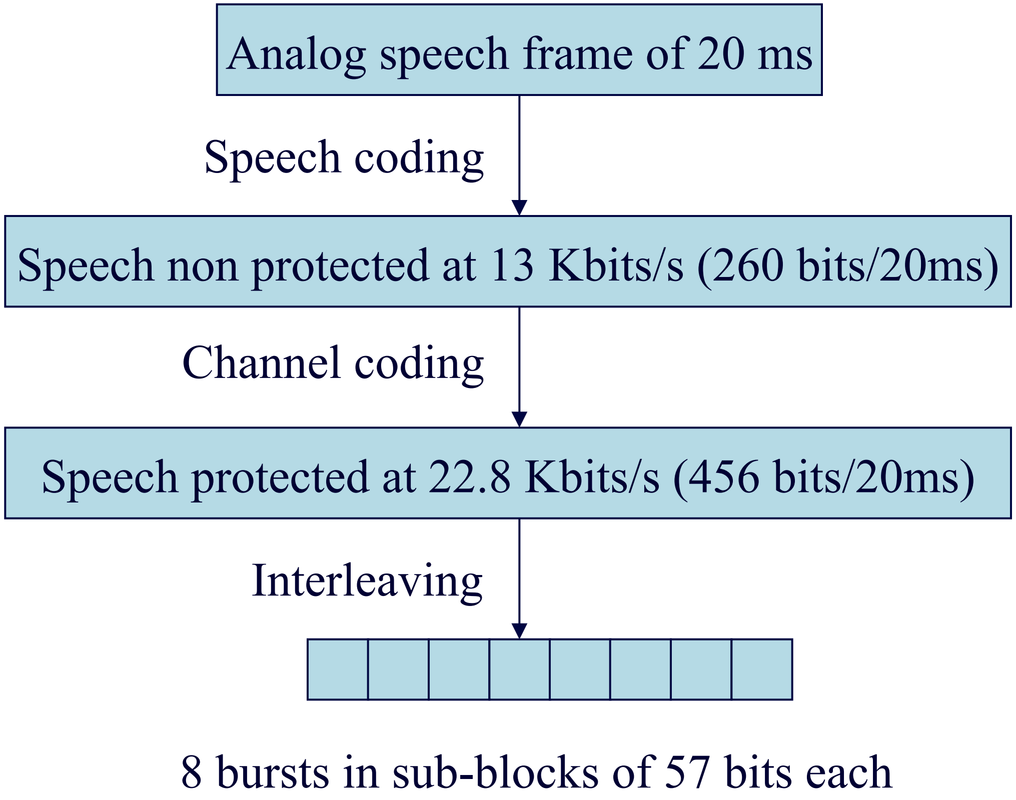



GSM timeslot:

- *Tail* (000): define start and end of a Burst
- *Training*: synchronization sequence with well-known bit pattern for adapting the receiver to the current signal propagation characteristics, e.g. calculating the strongest signal part in case of multipath propagation
- *S (Signaling)*: what is the content of the payload field: user or control data

# Signal processing for Traffic bursts

- The voice input is sampled at 8 kHz and coded at 13 bits/sample.
  - Take 20 ms analog speech frame
  - Represent it by 260 bits
  - The coding rate is (260 bit)/(0.02 seconds) = 13 kb/s.
- Channel coding to introduce redundancy into the data flow in order to allow the detection or the correction of bit errors introduced during the transmission.
- GSM blocks are interleaved on 8 bursts (57 bits each).
- The remaining 57 data bits (to complete the slot) represent the speech frame #i-1 or #i+1 (i.e., the previous or the next 20 ms sample).



# Logical Channels

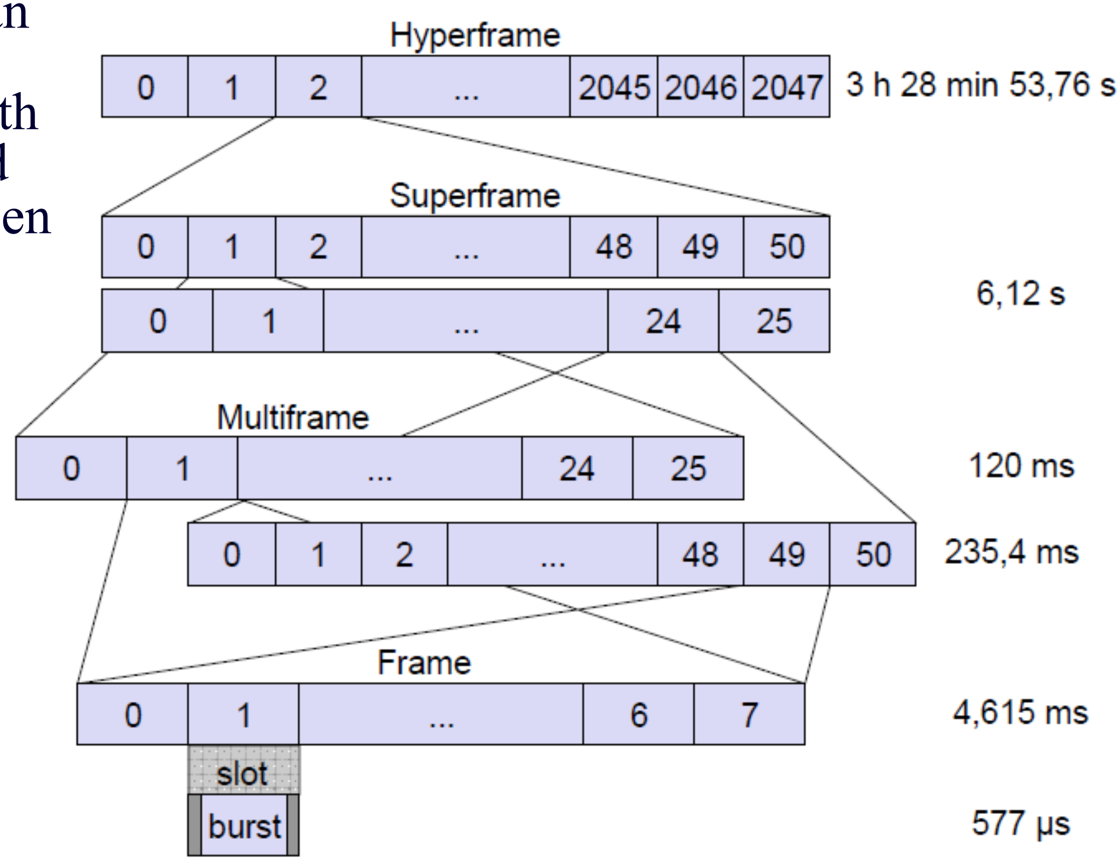
- Using one timeslot per TDMA frame to send one burst of data defines a *logical channel* for a device. But, the are different types of channels (with different burst structures):
- *Traffic Channels (TCH)*
  - Full-Rate Traffic Channels (TCH/F), defined as before
  - Half-Rate Traffic Channels (TCH/H), using only each second TDMA frame
- *Control Channels*
  - Standalone Dedicated Control Channel (SDCCH): for one traffic channel, e.g. for authentication, equipment validation, transfer of additional information as e.g. phone numbers, ... (only established if necessary)
  - Slow Associated Control Channel (SACCH): for one traffic channel, to do synchronization, maintenance, power regulation, handover initiation, … (exists all the time when the corresponding traffic channel is active)
  - Common Control Channels (CCCH) for paging of mobile stations, a slotted ALOHA based access procedure of MS for joining a GSM network
- *Broadcast Channels (BCH):* allow the base station to send frequency correction bursts with full power (to allow stations to adapt transmit power), synchronization bursts, information about channel structure and hopping sequences, …

# Frame Hierarchy

- So we have a large number of logical channels:
  - Traffic channels
  - Control channels for maintenance, requests of new stations to get assigned a channel, …
  - Broadcast channels for adaptation of all stations to the base station
- Result: complex frame hierarchy to come to a common time-structure in which all information is repeated

# Frame Hierarchy

- A frame has duration 4.615 ms. Consists of 8 slots. Each slot can accommodate one burst of duration 577 µs (156.25 bits with 114 bits for data and 8.25 guard bits to avoid overlapping between adjacent slots).
- Multiframe:
  - 26 frames (120 ms) or
  - 51 frames (235.4 ms)
- Superframe
  - 51 multiframes of 26 frames (6.12 s)
  - 26 multiframes of 51 frames (6.12 s)
- 2048 superframes form a hyperframe of duration 3 h 28 mn 53.76 s.



# Data Services in GSM

- Data transmission in GSM with only 4.8 resp. 9.6 kBit/s (depending on error protection)
- Advanced channel coding and reduced error-correction allows 14.4 kBit/s
- Still not enough for Internet access or even multimedia applications

- Thus: UMTS as "3G network": Integration of data and voice in one network
- But: new network infrastructure, new software, new devices, …
- Development of other enhancements of GSM as interim solutions

- "2.5G networks" as interim solution
  - *HSCSD* as software solution
  - *GPRS* as hardware solution
  - *EDGE* as 3G solution in a 2G network

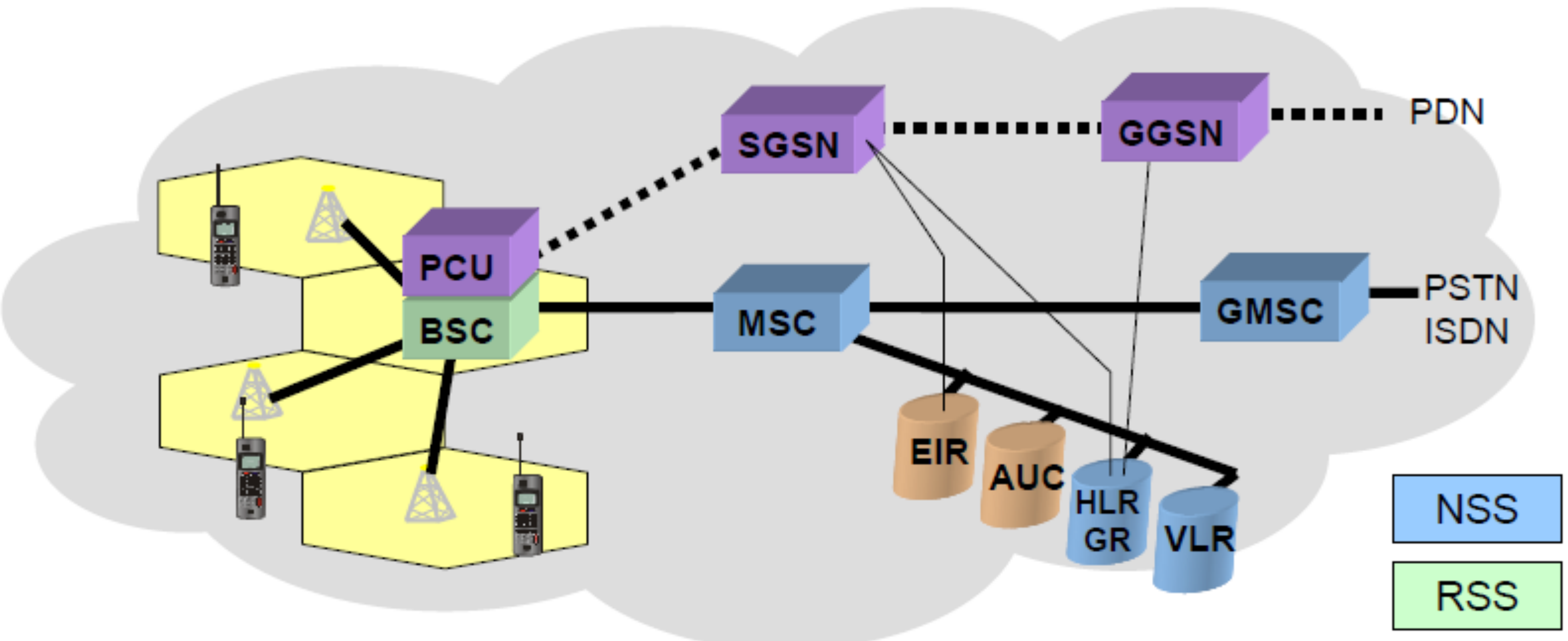
# High Speed Circuit Switching Data (HSCSD)

- Put together several time slots for one AIUR (Air Interface User Rate) up to 57.6 kBit/s with 4 Slots of 14.4 kBit/s.
- Symmetrical (2 time slots each for uplink and downlink) and asymmetrical (3 + 1 slots) communication are supported.
- Mainly software update for the realization of the putting together
- Advantage: fast availability, continuous quality, simple
- Disadvantage: connection-oriented, 4 channels are blocked the whole time, signaling for several channels necessary

# General Packet Radio System (GPRS)

- Packet-oriented transmission, usable also for multicast
- Usage of up to 8 time slots of a TDMA frame on demand
- Usage of time slots only when data are available for sending (e.g. 50 kBit/s with short usage of 4 slots)
- Advantage: step towards UMTS, flexible
- Disadvantage: expensive because some new infrastructure is needed to handle the new transmission mechanism, wireless transmission becomes a bottleneck for high traffic amount
- Needed infrastructure: GSN (GPRS Support Nodes) - GGSN and SGSN
  - GGSN (Gateway GSN): to connect the GPRS network to other IP networks (e.g., Internet).
  - SGSN (Serving GSN): to link between circuit switching nodes (GSM architecture) and GPRS network.
  - GR (GPRS Register): Management of user addresses

# GPRS architecture

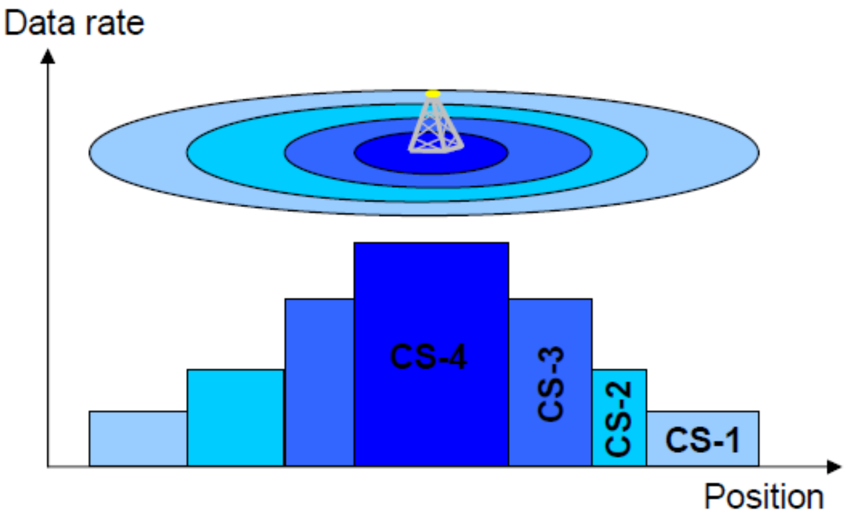



AUC: Authentication Center
BSC: Base Station Controller
EIR: Equipment Identity Register
GMSC: Gateway Mobile Switching Center
HLR: Home Location Register
MSC: Mobile Switching Center
VLR: Visitor Location Register

GGSN: Gateway GPRS Support Node
GR: GPRS Register
PCU: Packet Control Unit
SGSN: Serving GPRS Support Node

# Data rate increase

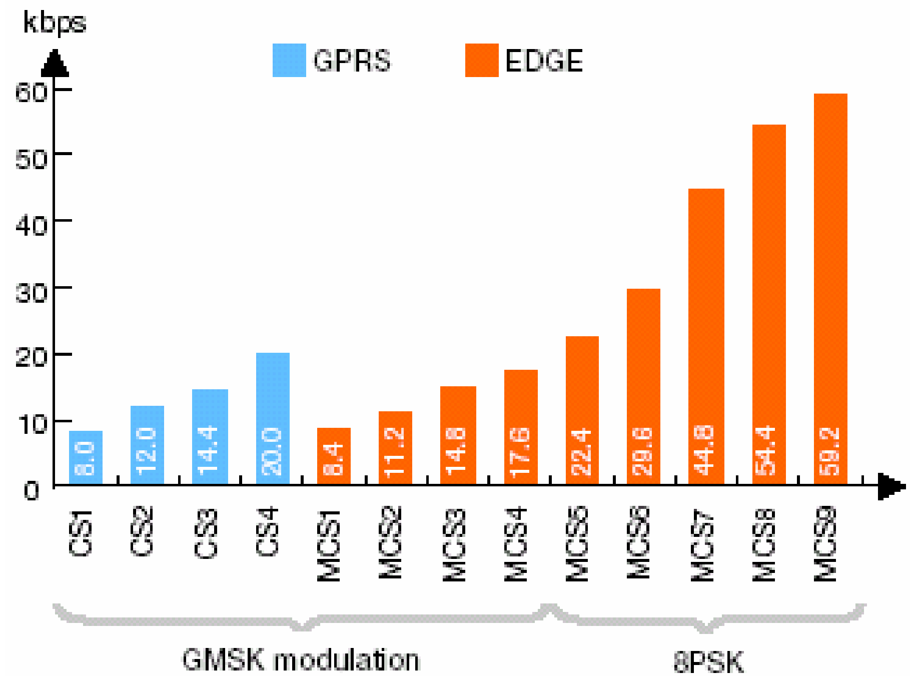
- In GSM, each terminal uses one slot allowing a data rate = 9.6 Kbit/s
- In GPRS, terminals can use multiple slots within the TDMA frame to transmit/receive data
  - Different coding with different level of data protection.
  - Dynamic choice of coding based on measurements of signal quality (and the needed QoS).
  - The user is assigned the highest possible data rate.
- Rates:
  - In theory: 171.2 Kbits/s. Optimal conditions: 8 slots for the terminal with CS-4 coding (8 * *21,4 = 171,2 kbits/s)*
  - Maximal available: 50 Kbits/s.




| Coding | Principle | Predictable rate per slot |
|---|---|---|
| CS-1 | Same speech protection as in GSM (strong protection) | 9,05 kbits/s |
| CS-2 | Protection slightly lower than that used in GSM | 13,4 kbits/s |
| CS-3 | Low protection | 15,6 kbits/s |
| CS-4 | Error detection without any correction (weak protection) | 21,4 kbits/s |

# Enhanced Data Rates for GSM Evolution (EDGE)

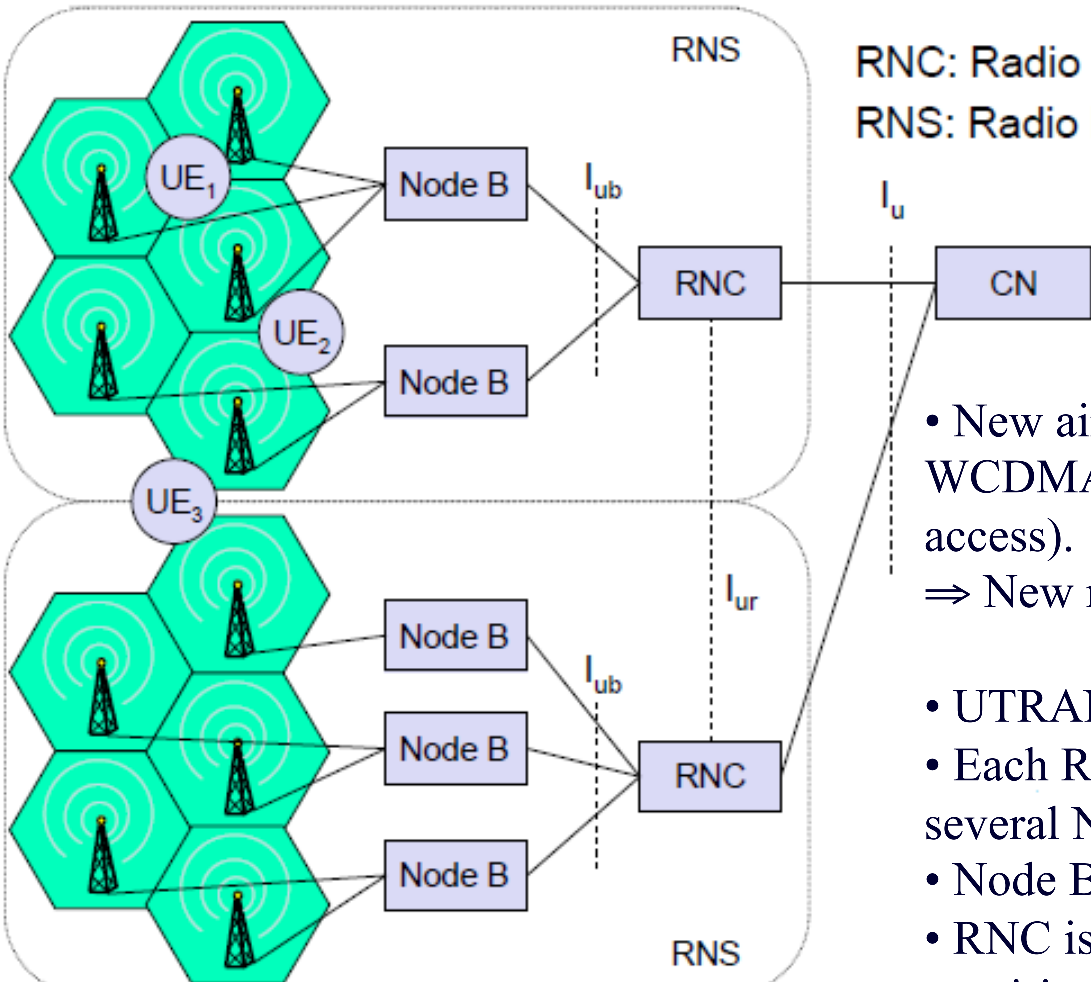
- Up to 384 kBit/s by enhanced modulation (8-PSK instead of GMSK)
- Transmission repeat:
  - Change of coding to adapt to the current channel quality
- Is build upon the existing GSM/ GPRS system:
  - New transceiver are needed (hardware upgrade in the BSS)
  - Software-Upgrade BSS and BSC
  - New devices (8PSK)
  - No changes in the core network!
  - Also possible: modulation similar to 16-QAM for higher data rate
- Cheap alternative to UMTS?



# Universal Mobile Telecommunications System (UMTS)

- Basis :
  - GSM next step, but using CDMA
  - Use the packet-basis for transmission
  - Offer high data rate for multimedia applications from 384 Kbits/s for urban outdoor up to 2 Mbits/s for indoor and low range outdoor
    - min. 144 kBit/s rural (target: 384 kBit/s)
    - min. 384 kBit/s suburban (target: 512 kBit/s)
    - up to 2 MBit/s urbanNew frequency bands :
  - 1885-2025 MHz (uplink), 2110-2200 MHz (downlink)
  - US: 1710-1755 MHz and 2110-2155 MHz
- Compatibility with GSM :
  - Old solution: 2 core networks – circuit switched for RT services and packet switched for other services
    - Use of IP/ATM in core networks
  - Change to one IP-based core network with release 5

# Universal Terrestrial Radio Access Network (UTRAN) architecture




RNC: Radio Network Controller

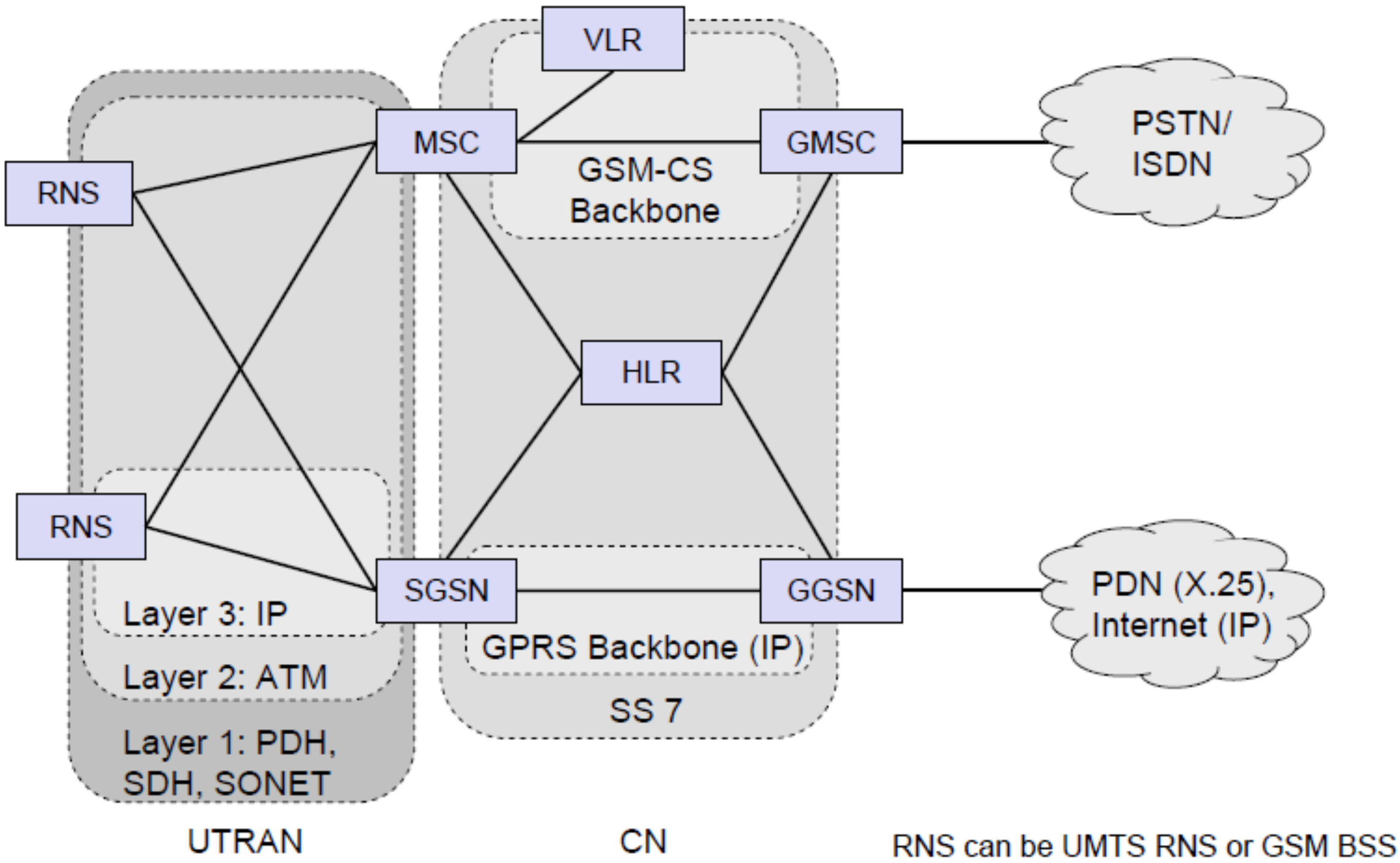
RNS: Radio Network Subsystem

- New air interface access method for UMTS: WCDMA (wide-band code division multiple access).

⇒ New radio access network (RAN): UTRAN

- UTRAN comprises several RNSs
- Each RNS is controlled by one RNC and several Node B.
- Node B provides service to multiple cells.
- RNC is responsible for handover decisions requiring signaling to the UE

# Core Network: Protocols



# Core Network: Protocols

- The Core Network and thus also the interface Iu are separated into two logical domains:
  - Circuit Switched Domain (CSD)
    - Circuit switched service inclusive signaling
    - Resource reservation at connection setup
    - GSM components (MSC, GMSC, VLR)
  - Packet Switched Domain (PSD)
    - GPRS components (SGSN, GGSN)
- Release 99/R4 uses the GSM/GPRS network and just adds a new radio access (use of IP/ATM in UTRAN)
  - Lower costs, faster deployment
  - Not as flexible as newer releases since R5 (change to IP based functions)

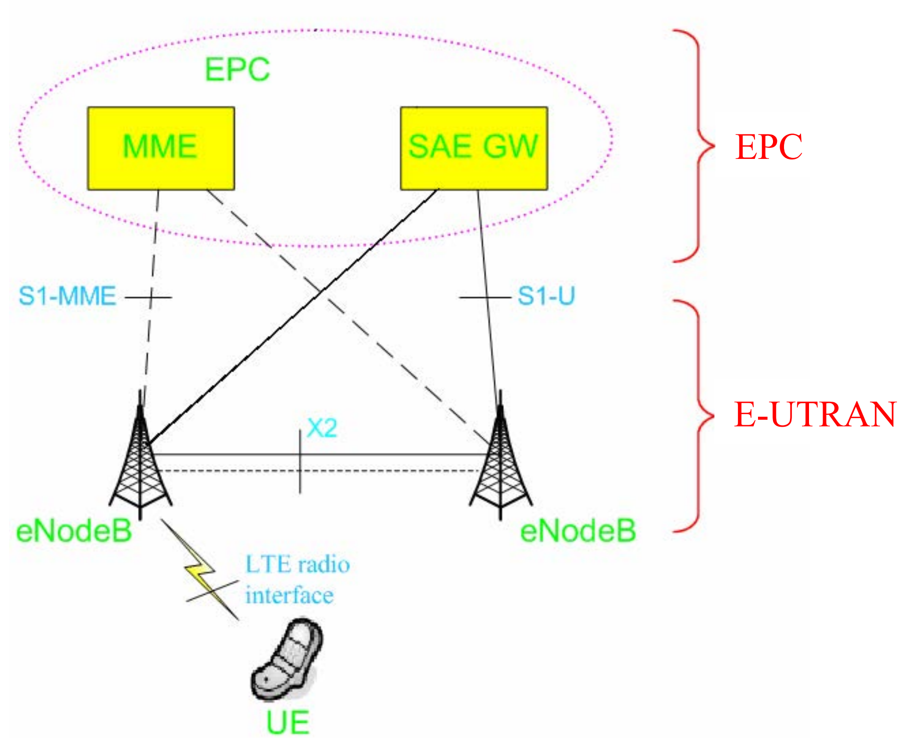
# More recent releases

- *Release 5*
  - Almost all-IP based core network for better integration with the Internet
  - Integration of IMS (IP Multimedia Subsystem) which should give guarantees in an IP-based network necessary for voice transmission
  - Adaptive rate codec for better quality of the transmitted speech
  - High-speed transmission on the radio interface (HSDPA, up to 10 MBit/s downlink)
- *Release 6*
  - High-speed uplink (HSUPA) in analogy to HSDPA
  - UMTS/WLAN interworking
  - Fast cell selection, security enhancements, first mentioning of OFDM, …
- *Release 7*
  - HSDPA improvement by MIMO
  - Advanced coding with 64QAM (downlink), 16QAM (uplink)
  - QoS on UMTS/WLAN
  - New frequency ranges, …
- *Release 8*
  - Long Term Evolution (LTE) as HSPA enhancement with 100 MBit/s (downlink) and 50 MBit/s (uplink)
  - How? By making use of MIMO/64QAM – and using OFDMA…

# 4G networks: LTE architecture

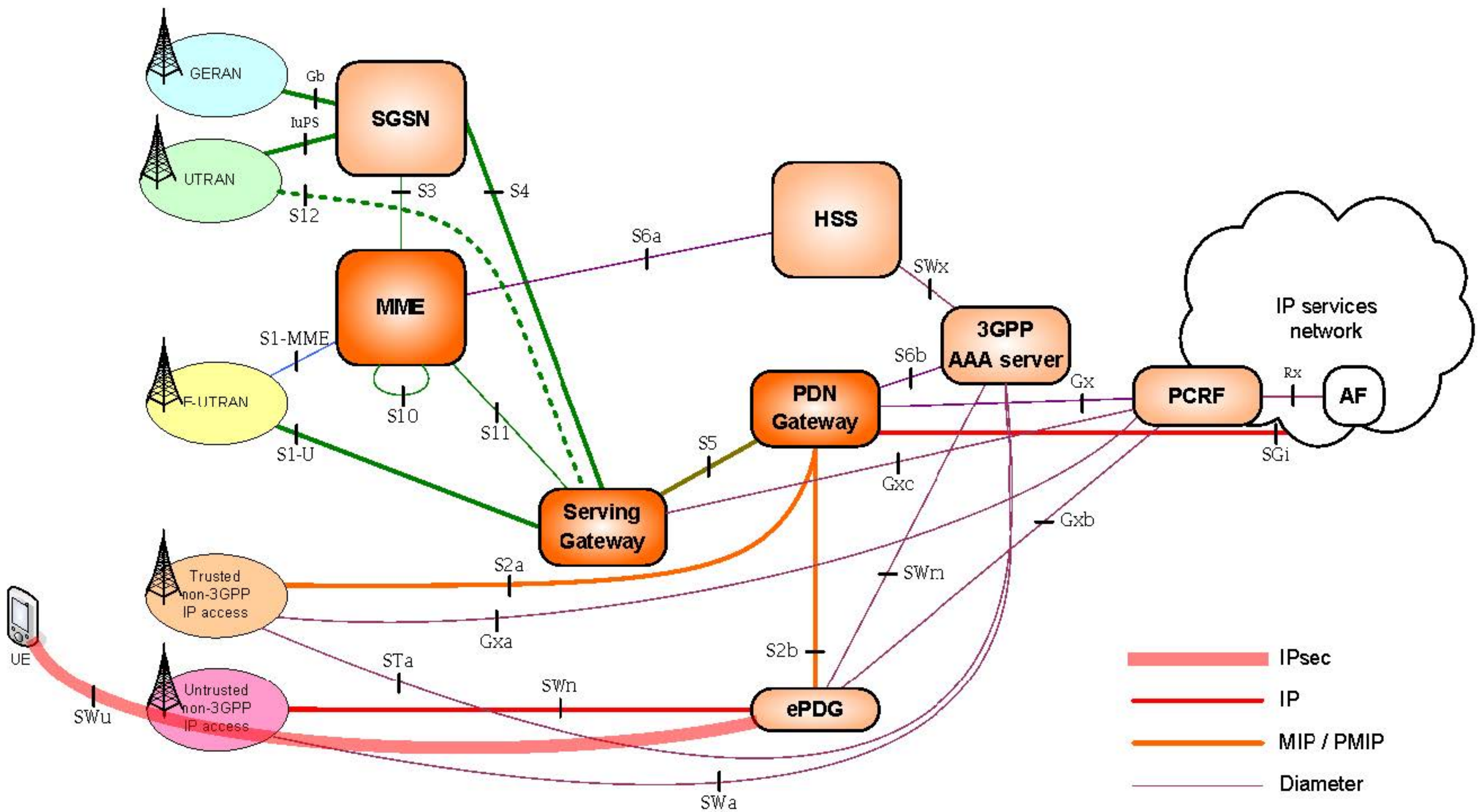
- Access Network: Evolved-UTRAN:
  - No RNC usage: flat architecture
  - Supported functionalities of RNC distributed between eNodeB and network elements in the Core Network.

- Core Network: SAE (system Architecture Evolution)
  - SAE is the name of the project, the core network is called EPC (Evolved Packet Core)
  - MME: control plane
  - S-GW: data plane
  - Multiple access IP architecture

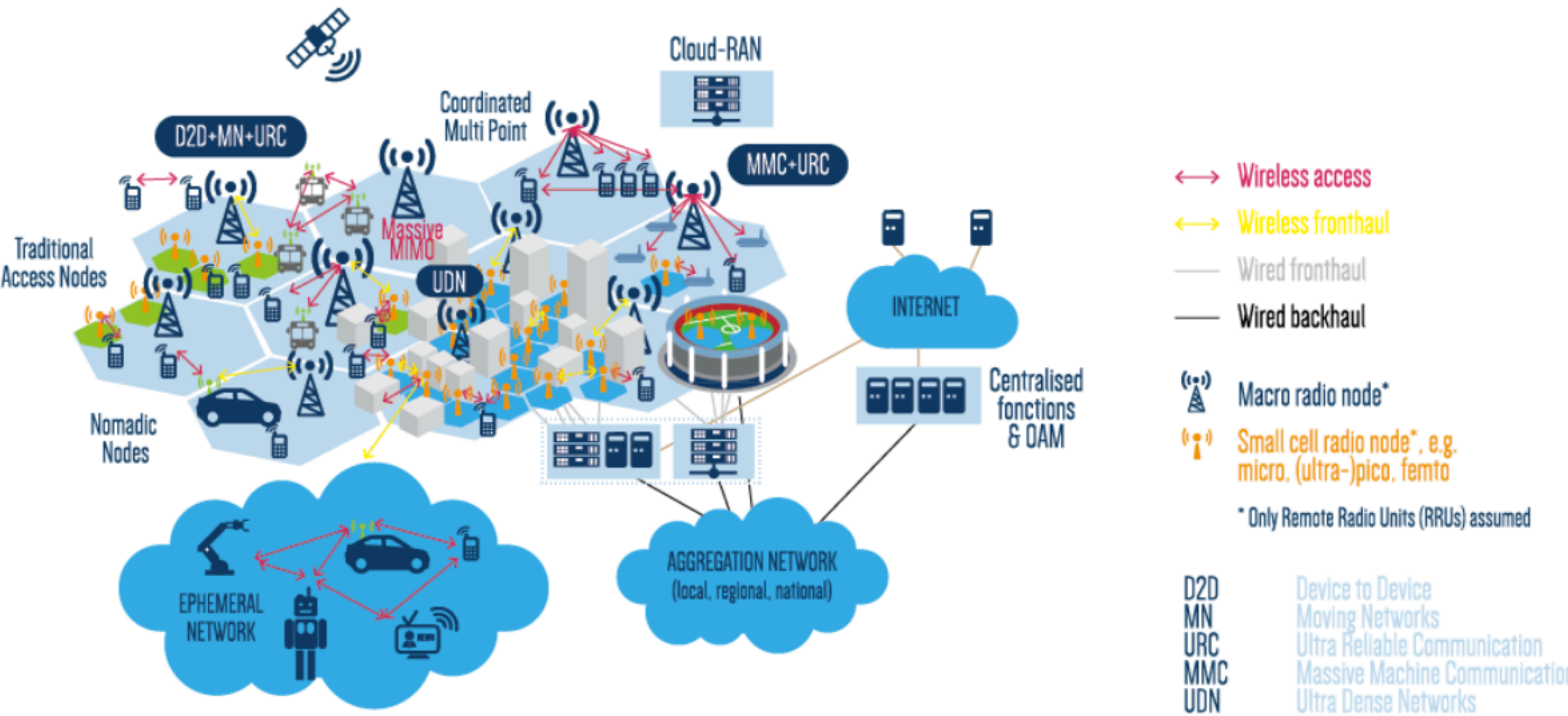



- eNodeB: evolved Node B
- MME: Mobility Management Entity
- S-GW: Serving Gateway

# More complex EPC architecture



# What is Next: 5G?




Source: 5G Infrastructure Association: Vision White Paper, February 2015.

# Cloud-RAN for 5G: motivations and goal

To meet growing data traffic demands mobile network operators have to increase network capacity

**How?**

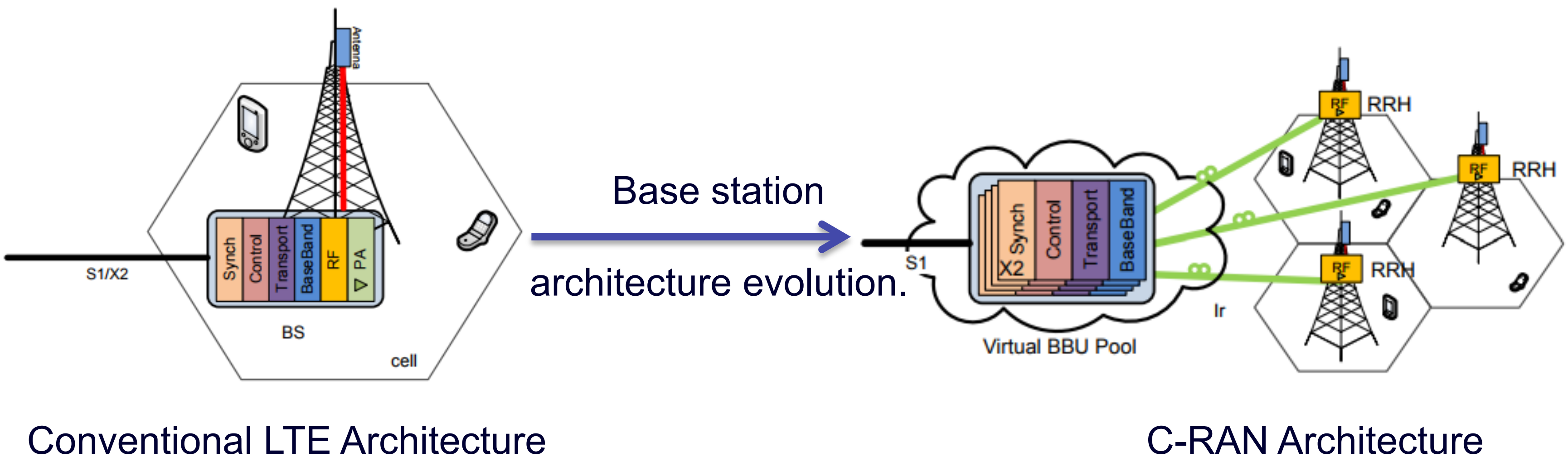
- By adding more cells
- And/or by implementing MIMO techniques where numerous antennas simultaneously serve a number of users in the same time frequency resource.

This results in growing inter-cell interference levels and higher costs

Need to re-think network infrastructure: **C-RAN**

# C-RAN: definition

- Cloud-RAN is first proposed by [CMI] in 2013, detailed by [NGMN] in 2015.
- C-RAN is a novel network architecture where **baseband (BB) resources are pooled and shared** between base stations.
- A **high bandwidth low-latency optical network** connects RRHs to the BBU pool.
- **CPRI** is the radio interface protocol for data transmission from BBU to RRH.

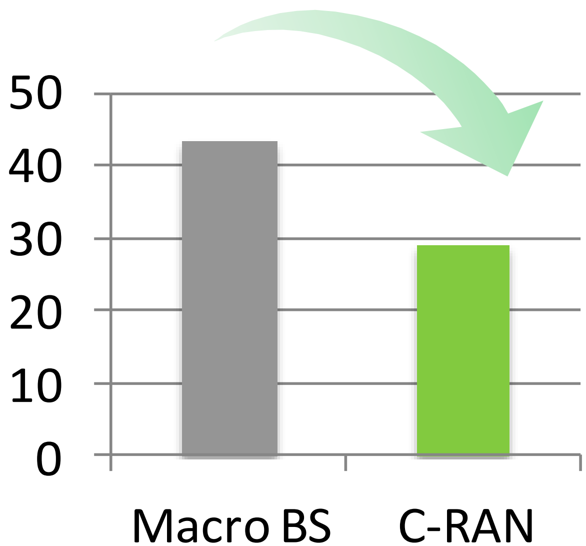



[CMI] China Mobile Research Institute "C-RAN, The Road Towards Green RAN", in White Paper, 2013
[NGMN] NGMN Alliance "Further study on critical C-RAN technologies", in White Paper, 2015

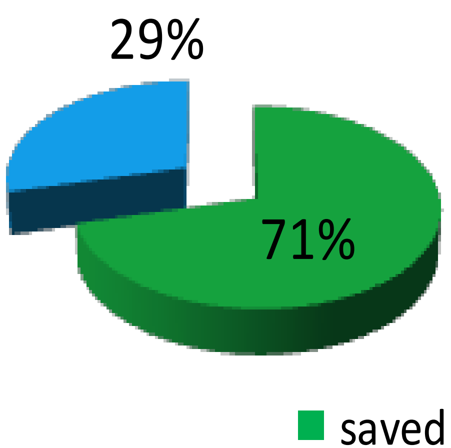
# C-RAN benefits

- Centralized BBU Pool:
  - Reduces cost of base stations deployment and operation
  - Reduces power consumption
  - Increases flexibility in network upgrades
  - Enables better coordination and interference management

Construction cost per site reduced by 1/3




Power consumption reduced by at most 71%




*Source: Base on China Mobile field trial surveys

# C-RAN benefits

- C-RAN + Virtualization:
  - ✓ Gives operators the chance to execute RAN functionalities on a generic data center environment, enabling them to offer more costly-efficient services:
    - ➢ RANaaS
  - ✓ Enables different network architecture functional splits including different levels of functionality implemented as NFVs (Network Functions Virtualization):
    - ➢ Network Slicing

# C-RAN challenges

- **Dynamic resource allocation and power minimization:**
  - ✓ Mobile users traffic demands, profiles, and QoS requirements
  - ✓ Dynamic BBU-RRH association
  - ✓ Fronthaul links capacity
  - ✓ BBU virtualization cost

- **Dynamic Functional splits:**
  - ✓ Centralizing more BBU functions in the Cloud enables less cost, less energy consumption, but increases traffic load on the Fronthaul.
  - ✓ Decentralization of some BBU functions will relax the burden on the Fronthaul but makes executing them on the access site and so increases the cost and energy consumption.

Thanks for your attention

Questions ?