# Universal Mobile Telecommunications System (UMTS)

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AP/CSE

# Evolution : From 2G to 3G



- Services must be independent from radio access technology and is not limited by the network infrastructure.
- Support of multimedia and all of its components.
- Increased data rate.
- Convergence of existing networks.
- Video Telephony.
- MP3 downloads.
- Potential good applications like TV on a mobile phone.
- However, to convert to UMTS, the network needs to be reengineered from the ground up.
  - Actually uses the lower 3 layers of the OSI model.

# Evolution : From 2G to 3G



- GPRS – General Packet Radio Services
  - 2.5G protocol
  - Involved only software changes to the GSM network.
  - Used under utilized TDMA channels more effectively.
  - Increased data rates to a max of 170 Kbps.
- EDGE – Enhanced Data rates for GSM Evolution.
  - 2.75G protocol.
  - Required minimal hardware changes
  - Added a new encoding scheme that allowed for more bits to be added into each time slice.
  - Data can now be passed optimally at 384 Kbps.
- Both of these use TDMA over GSM

# UMTS



- 3G Standard for Cellular Communication
- Uses W-CDMA (Wideband CDMA)
  - 5 MHz of bandwidth for each channel.
  - Several thousand users can be supported on each cell site.
- Offers 11 Mbps download speeds in theory.
  - Uplink speeds are much slower
  - Most users are finding download throughput of about 384 Kbps.
    - However, this is still much faster than the 14.4 Kbps optimally that GSM offered.

# UMTS - Standards

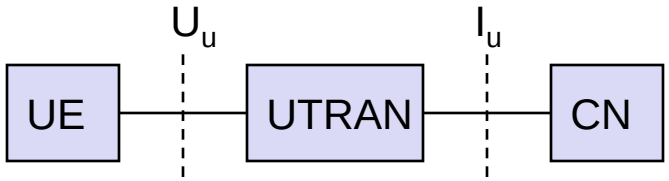


- The 3G standard was written by the International Telecommunication Union (ITU)
  - The standard is referred as IMT-2000 (International Mobile Telecommunications for the year 2000)
- The key to the standards is the available data over the air interface
  - 2 Mbps in fixed or in-building environments
  - 384 kbps in pedestrian or urban environments
  - 144 kbps in wide area mobile environments
  - Variable data rates in large geographic area systems (satellite)

# UMTS Architecture

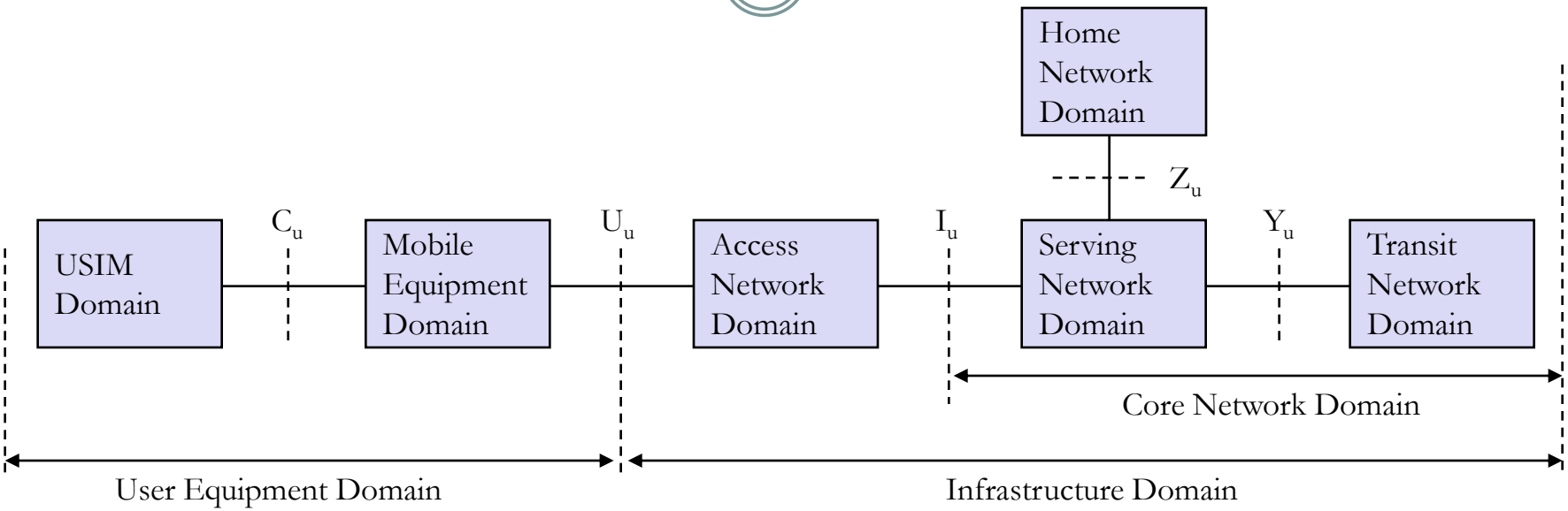


- UE (User Equipment)
- UTRAN (UMTS Terrestrial Radio Access Network)
  - Cell level mobility
  - Radio Network Subsystem (RNS)
  - Encapsulation of all radio specific tasks
- CN (Core Network)
  - Inter system handover
  - Location management if there is no dedicated connection between UE and UTRAN



# UMTS Domains and Interfaces






- User Equipment Domain
  - Assigned to a single user in order to access UMTS services
- Infrastructure Domain
  - Shared among all users
  - Offers UMTS services to all accepted users

# UMTS Domains and Interfaces



- Universal Subscriber Identity Module (USIM)
  - Functions for encryption and authentication of users
  - Located on a SIM inserted into a mobile device
- Mobile Equipment Domain
  - Functions for radio transmission
  - User interface for establishing/maintaining end-to-end connections
- Access Network Domain
  - Access network dependent functions
- Core Network Domain
  - Access network independent functions
  - Serving Network Domain
    - Network currently responsible for communication
  - Home Network Domain
    - Location and access network independent functions

# UMTS Radio Interface

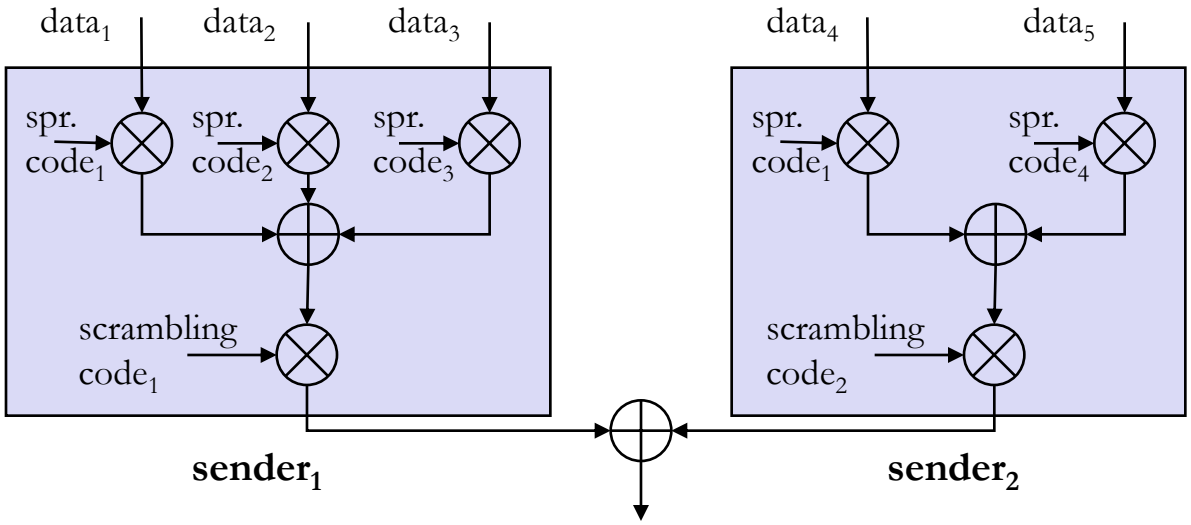


- Spreading and scrambling of user data
- OVSF coding (orthogonal variable spreading factor)
- UMTS FDD frame structure (WCDMA)
- UMTS TDD Frame Structure

# Spreading and scrambling of user data

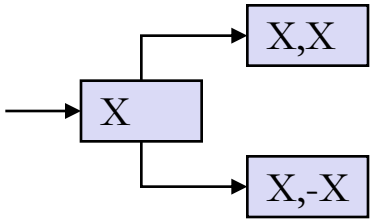


- Constant chipping rate of 3.84 Mchip/s
- Different user data rates supported via different spreading factors
  - higher data rate: less chips per bit and vice versa
- User separation via unique, quasi orthogonal scrambling codes
  - users are not separated via orthogonal spreading codes
  - much simpler management of codes: each station can use the same orthogonal spreading codes
  - precise synchronization not necessary as the scrambling codes stay quasi-orthogonal

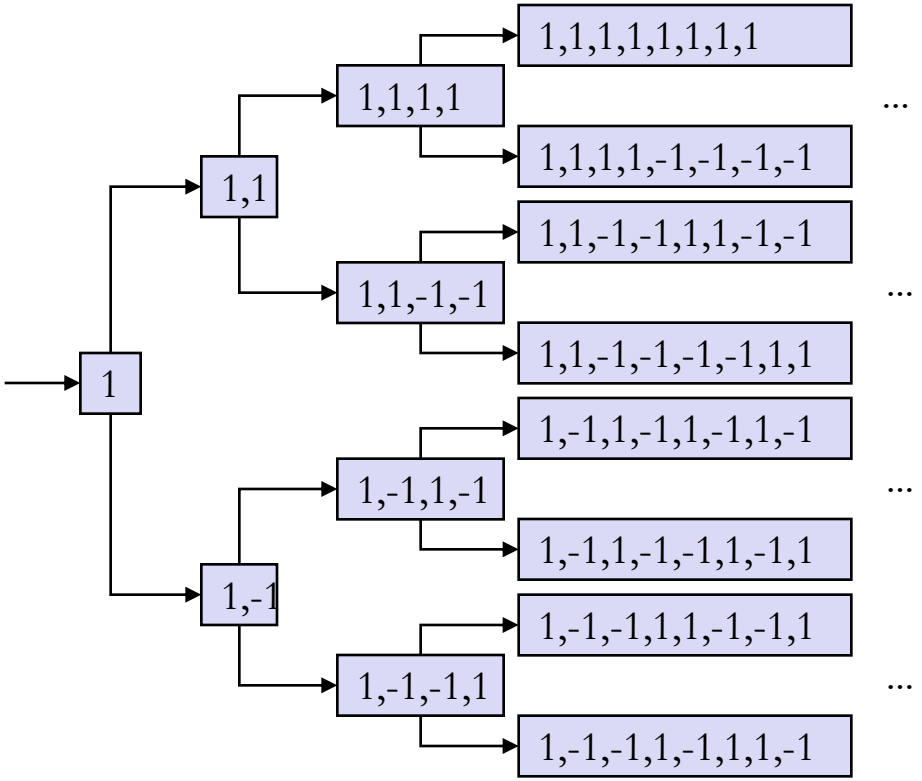


# OVSF coding





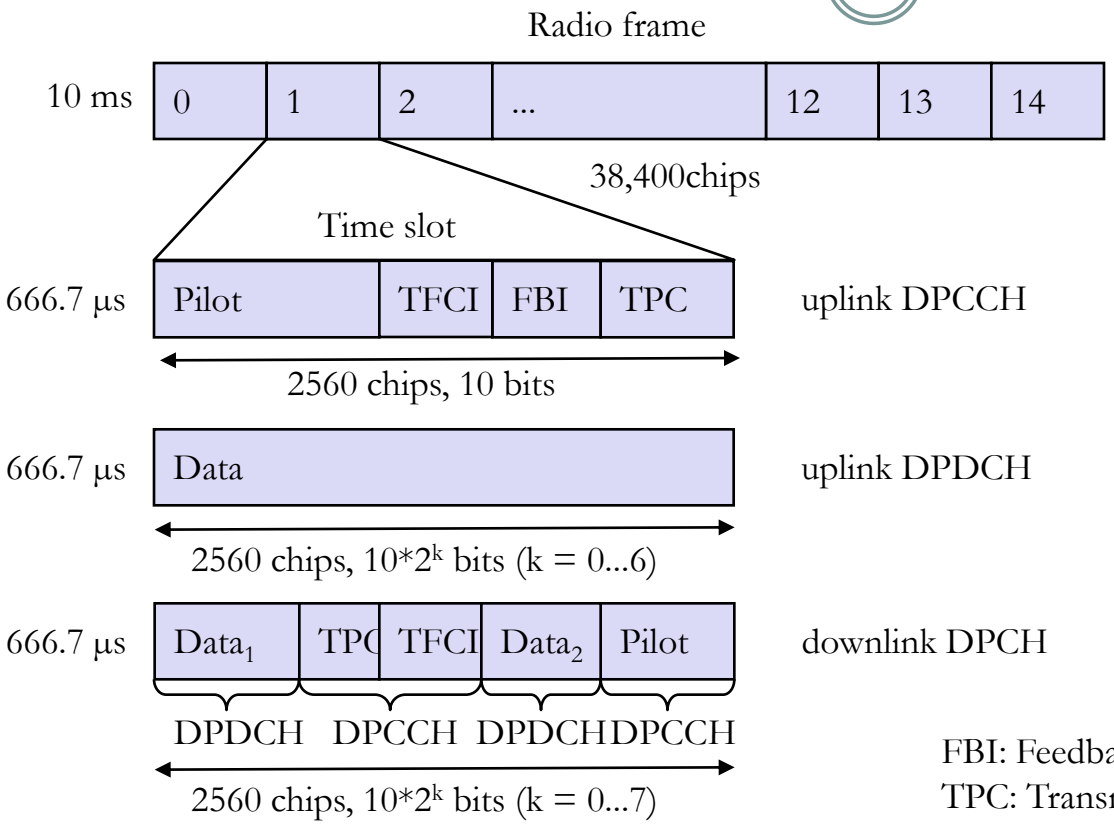

SF=n SF=2n




SF=1 SF=2 SF=4 SF=8

# UMTS FDD Frame Structure (W-CDMA)






**W-CDMA**

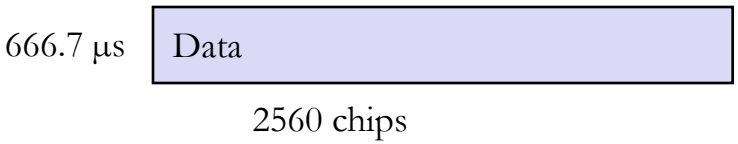
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate: 3.840 Mchip/s
- soft handover
- QPSK
- spreading factor: UL: 4-256; DL:4-512

FBI: Feedback Information
TPC: Transmit Power Control
TFCI: Transport Format Combination Indicator
DPCCH: Dedicated Physical Control Channel
DPDCH: Dedicated Physical Data Channel
DPCH: Dedicated Physical Channel

# Dedicated Physical Data Channel



- Offered Data Rates
  - 960 kbps, 480, 240, 120, 60, 30, and 15 kbps (spreading factor 256).
- 960 kbps
  - spreading factor 4,
  - 640 bits per slot,
  - 15 slots per frame,
  - 100 frames



# Typical UTRA-FDD uplink data rates

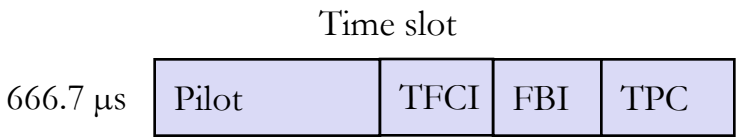


| **User data rate [kbit/s]** | **12.2 (voice)** | **64** | **144** | **384** |
|---|---|---|---|---|
| DPDCH [kbit/s] | 60 | 240 | 480 | 960 |
| DPCCH [kbit/s] | 15 | 15 | 15 | 15 |
| Spreading | 64 | 16 | 8 | 4 |

# Dedicated Physical Control Channel



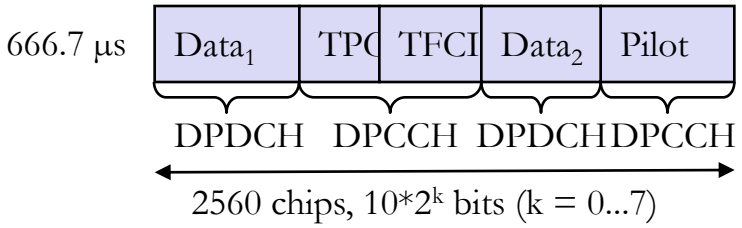
- Constant spreading factor 256
- Pilot is used for channel estimation.
- Transport Format Combination Identifier (TFCI) specifies the channels transported within the DPDCHs.
- Feedback Information Field (FBI) supports soft handover.
- Transmit Power Control (TPC) is used for controlling the transmission power of a sender



# Dedicated Physical Channel

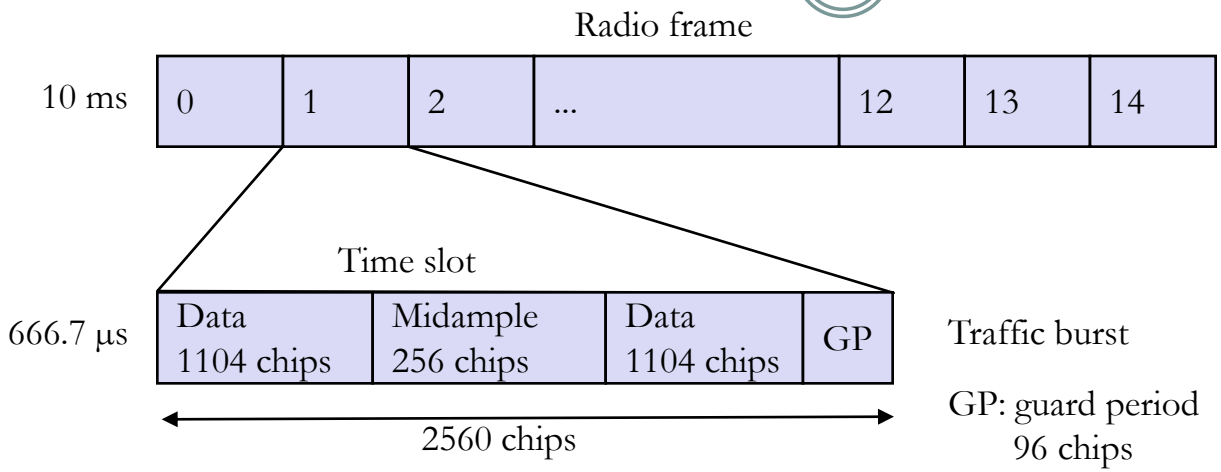


- Spreading factors between 4 and 512 are available
- data rates for data channels (DPDCH) within a DPCH are
  - 6 kbit/s (SF=512),
  - 24 kbit/s
  - 51 kbit/s
  - 90 kbit/s
  - 210,
  - 432,
  - 912,
  - 1,872 kbit/s (SF=4)



# UMTS TDD Frame Structure



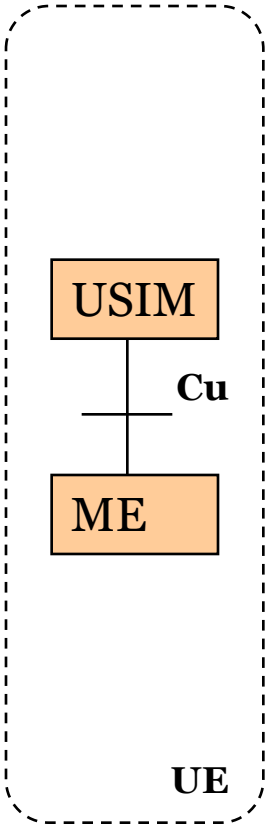



**TD-CDMA**

- 2560 chips per slot
- spreading factor: 1-16
- symmetric or asymmetric slot assignment to UL/DL (min. 1 per direction)

# User Equipment Architecture






- User Equipment → any UMTS enabled mobile device
- User Equipment Domain handles the access of the user onto the UMTS services
- USIM – User Services Identity Module
  - Extended SIM functionality
  - Functions for user identification, authentication and encryption
  - Integrated into SIM card (of the established format)
  - Most recent Mobile Equipment can handle both SIM and USIM
- Mobile Equipment Domain responsible for air interface
  - User interface for end-to-end connections

# UE – User Equipment



- The UE is the counterpart of several nodes of the architecture.
- As the counterpart of a node B, the UE performs
  - Signal quality measurements, inner loop power control, spreading and modulation, and rate matching.
- As a counterpart of the RNC, the UE
  - Has to cooperate during handover and cell selection, performs encryption and decryption, and participates in the radio resource allocation process.
- As a counterpart of the CN, the UE
  - Has to implement mobility management functions, performs bearer negotiation, or requests certain services from the network.

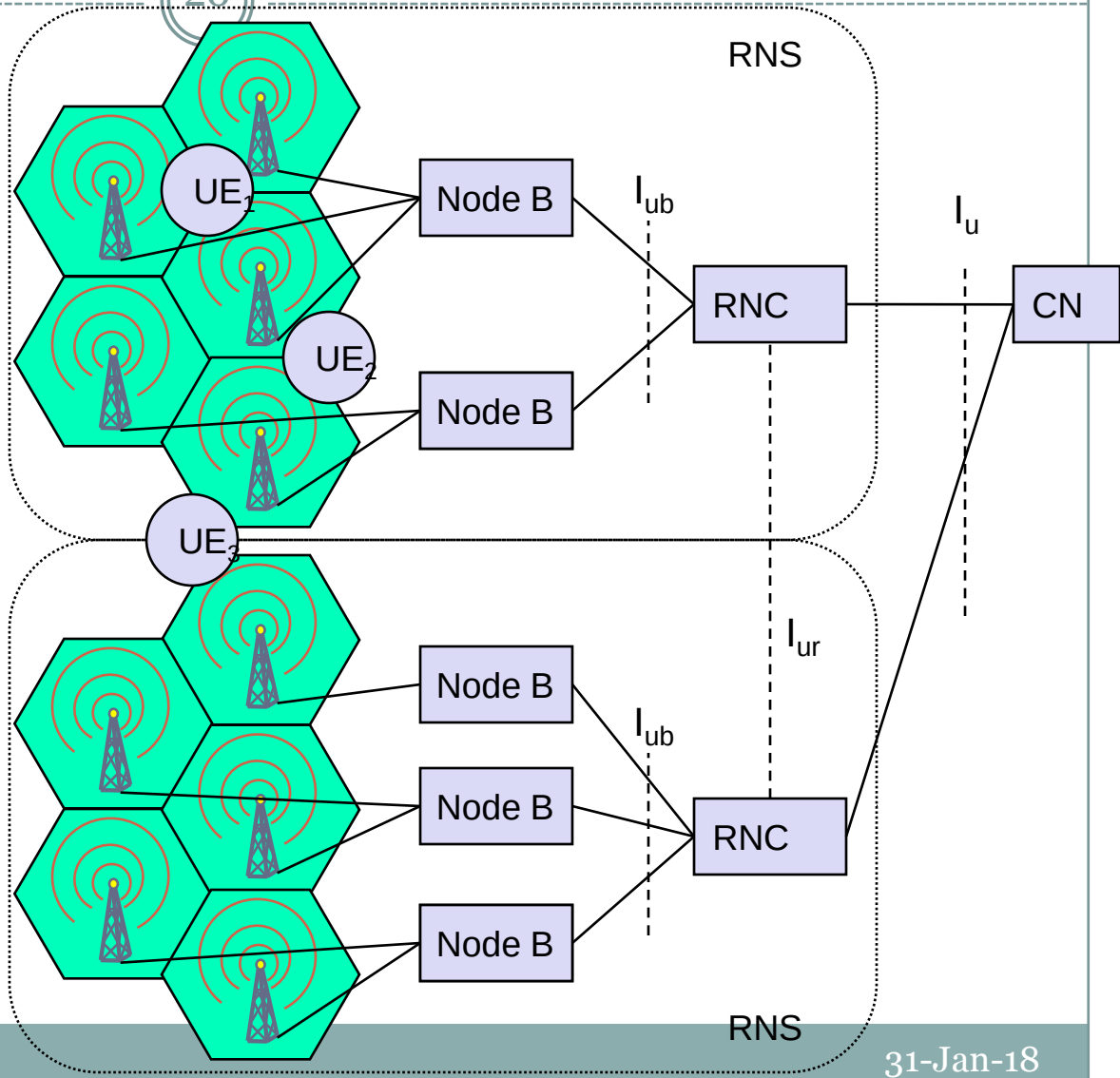
# UTRAN Architecture



RNC: Radio Network Controller

RNS: Radio Network Subsystem

- UTRAN comprises several RNSs
- Node B can support FDD or TDD or both
- RNC is responsible for handover decisions requiring signaling to the UE
- Cell offers FDD or TDD



# Radio Network Controller



- Call admission control
  - The RNC calculates the traffic within each cell and decides, if additional transmissions are acceptable or not
- Congestion control
  - The RNC allocates bandwidth to each station in a cyclic fashion and must consider the QoS requirements
- Encryption/Decryption
  - The RNC encrypts all data arriving from the fixed network before transmission over the wireless link (and vice versa)
- ATM switching and multiplexing, protocol conversion
  - The connections between RNCs, node Bs, and the CN are based on ATM. An RNC has to switch the connections to multiplex different data streams.
- Radio bearer setup and release
  - An RNC has to set-up, maintain, and release a logical data connection to a UE

# Radio Network Controller



- Code allocation
  - The CDMA codes used by a UE are selected by the RNC
- Power control
  - The RNC only performs a relatively loose power control (the outer loop).
  - This outer loop of power control helps to minimize interference between neighbouring cells or controls the size of a cell
- Handover control and RNS relocation
  - Depending on the signal strengths received by UEs and node Bs, an RNC can decide if another cell would be better suited for a certain connection
- Management
  - The network operator needs a lot of information regarding the current load, current traffic, error states etc. to manage its network

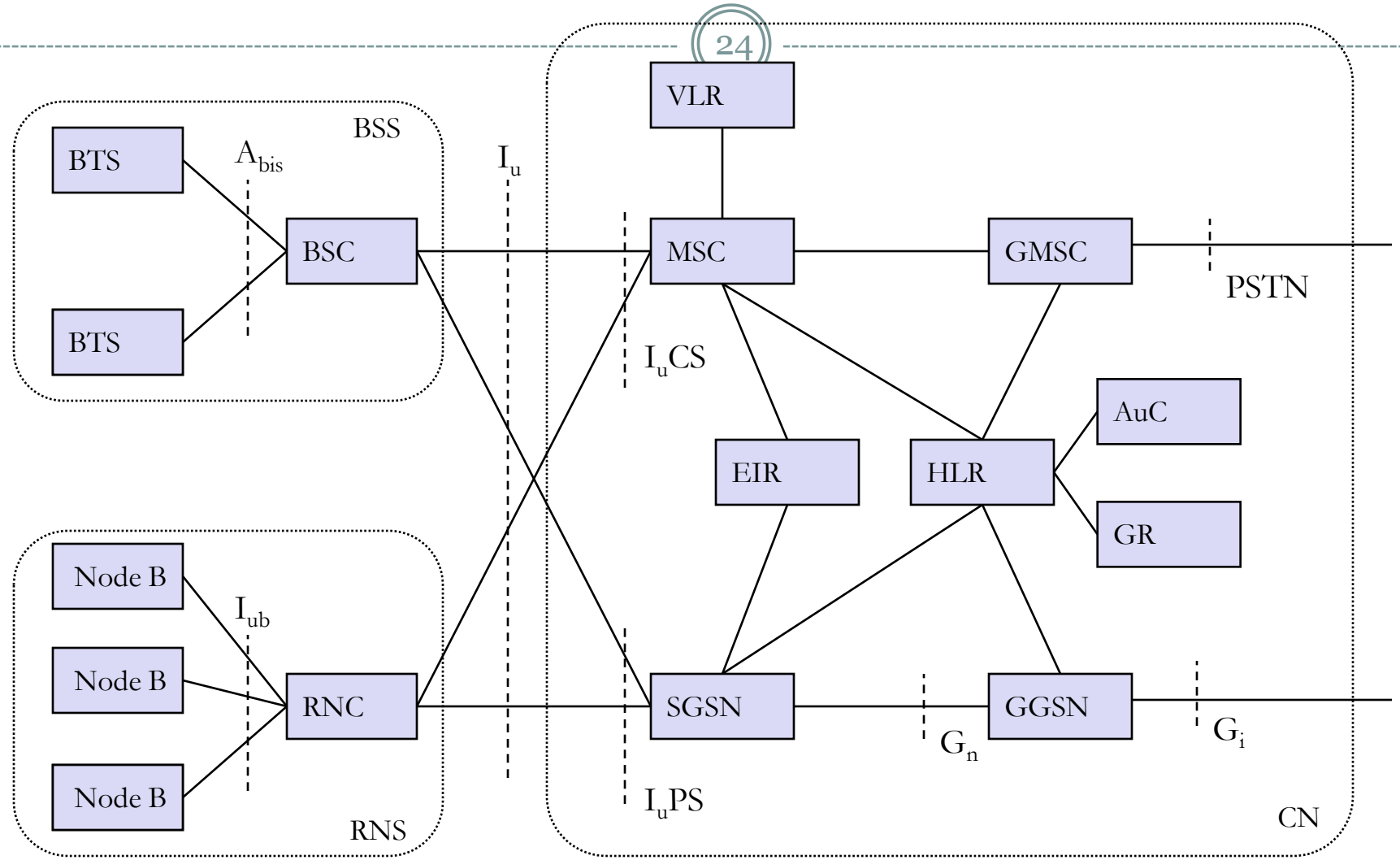
# Node B



- Node B connects to one or more antennas creating one or more cells.
- The cells can either use FDD or TDD or both
- An important task of a node B is the inner loop power control to mitigate near-far effects.
- Node B also measures connection qualities and signal strengths
- Node B can even support a special case of handover, a so-called softer handover which takes place between different antennas of the same node B

# Core Network Architecture





# Core Network Architecture



- The Core Network (CN) and thus the Interface $I_u$, too, are separated into two logical domains:
- Circuit Switched Domain (CSD)
  - Circuit switched service incl. signaling
  - Resource reservation at connection setup
  - GSM components (MSC, GMSC, VLR)
  - $I_u$CS
  - Mobile Switching Centre (MSC)
    - Switching CS transactions
  - Visitor Location Register (VLR)
    - Holds a copy of the visiting user's service profile, and the precise info of the UE's location
  - Gateway MSC (GMSC)
    - The switch that connects to external networks
  - Home Location Register (HLR)
    - Stores master copies of users service profiles
    - Stores UE location on the level of MSC/VLR/SGSN
- Packet Switched Domain (PSD)
  - GPRS components (SGSN, GGSN)
  - $I_u$PS
  - Serving GPRS Support Node (SGSN) (Similar function as MSC/VLR)
  - Gateway GPRS Support Node (GGSN) (Similar function as GMSC)

# UMTS Handover



- Hard Handover
- Soft Handover
- Softer Handover

# Hard Handover



- All the old radio links in the UE are removed before the new radio links are established.
- Inter Frequency Handover
  - Changing the carrier frequency, is a hard handover
  - Receiving data at different frequencies at the same time requires a more complex receiver
- Inter System Handovers
  - Handovers to and from GSM or other IMT-2000 systems

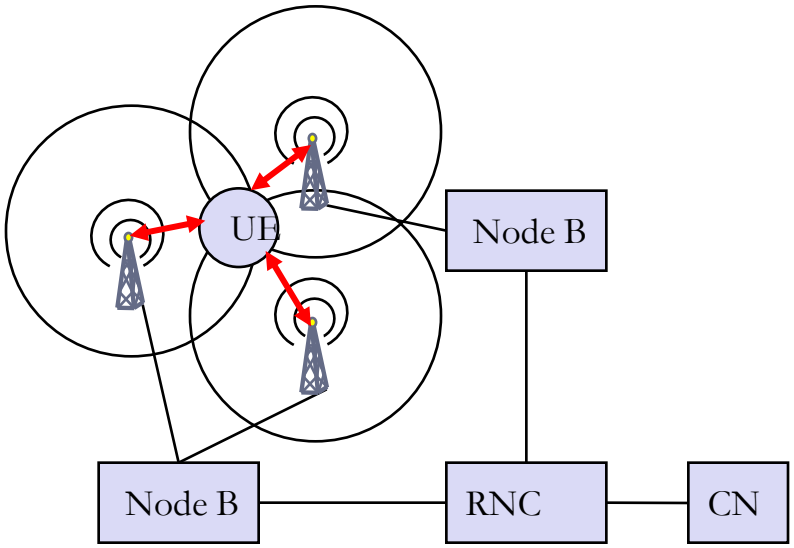
# Soft Handover



- Soft handover means that the radio links are added and removed in a way that the UE always keeps at least one radio link to the UTRAN
- Soft handovers are well known from traditional CDMA networks as they use macro diversity, a basic property of
- CDMA

# Support of Mobility: Macro Diversity






- UE can receive signals from up to three different antennas, which may belong to different node Bs.
- Downlink
  - The RNC splits the data stream and forwards it to the node Bs.
  - The UE combines the received data again.
- Uplink
  - UE simply sends its data which is then received by all node Bs involved.
  - The RNC combines the data streams received from the node Bs.
- The fact that a UE receives data from different antennas at the same time makes a handover soft.
- Moving from one cell to another is a smooth

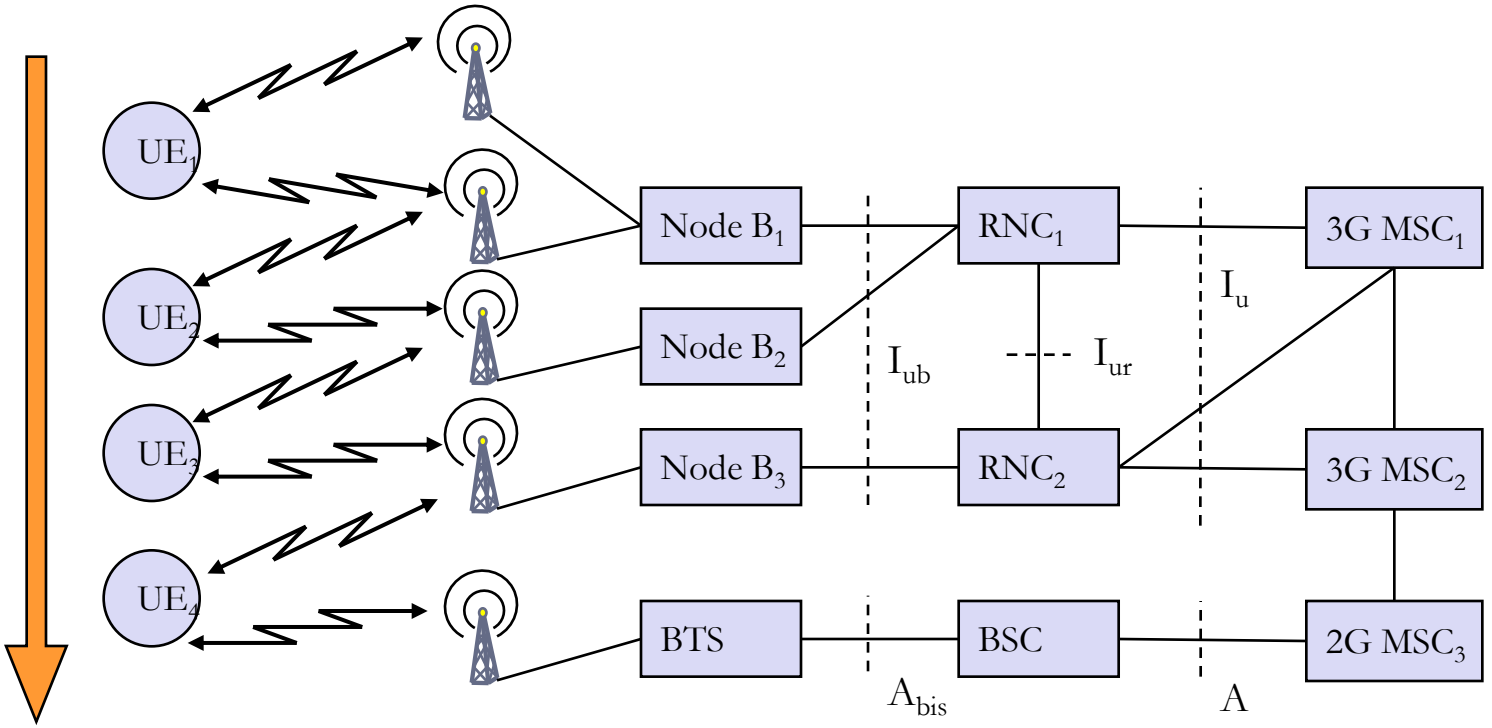
# Softer Handover



- Softer handover is a special case of soft handover where the radio links that are added and removed belong to the same Node B

# Handover Types in UMTS





# Handover Types in UMTS



- Intra-node B, intra-RNC
  - UE1 moves from one antenna of node B1 to another antenna. This type of handover is called softer handover.
  - In this case node B1 performs combining and splitting of the data streams.
- Inter-node B, intra-RNC:
  - UE2 moves from node B1 to node B2.
  - In this case RNC1 supports the soft handover by combining and splitting data.
- Inter-RNC
  - When UE3 moves from node B2 to node B3 two different types of handover can take place.
  - internal inter-RNC handover and external inter-RNC handover.
- Inter-MSC
  - MSC2 takes over and performs a hard handover of the connection.
- Inter-system
  - UE4 moves from a 3G UMTS network into a 2G GSM network.
  - This is hard handover.

# QoS Classes



| Traffic class | Conversational class | Streaming class | Interactive class | Background |
|---|---|---|---|---|
| **Fundamental characteristics** | Preserve time relation between information entities of the stream<br><br>Conversational pattern (stringent and low delay) | Preserve time relation between information entities of the stream | Request response pattern<br><br>Preserve data integrity | Destination is not expecting the data within a certain time<br><br>Preserve data integrity |
| **Example of the application** | Voice, videotelephony, video games | Streaming multimedia | Web browsing, network games | Background download of emails |

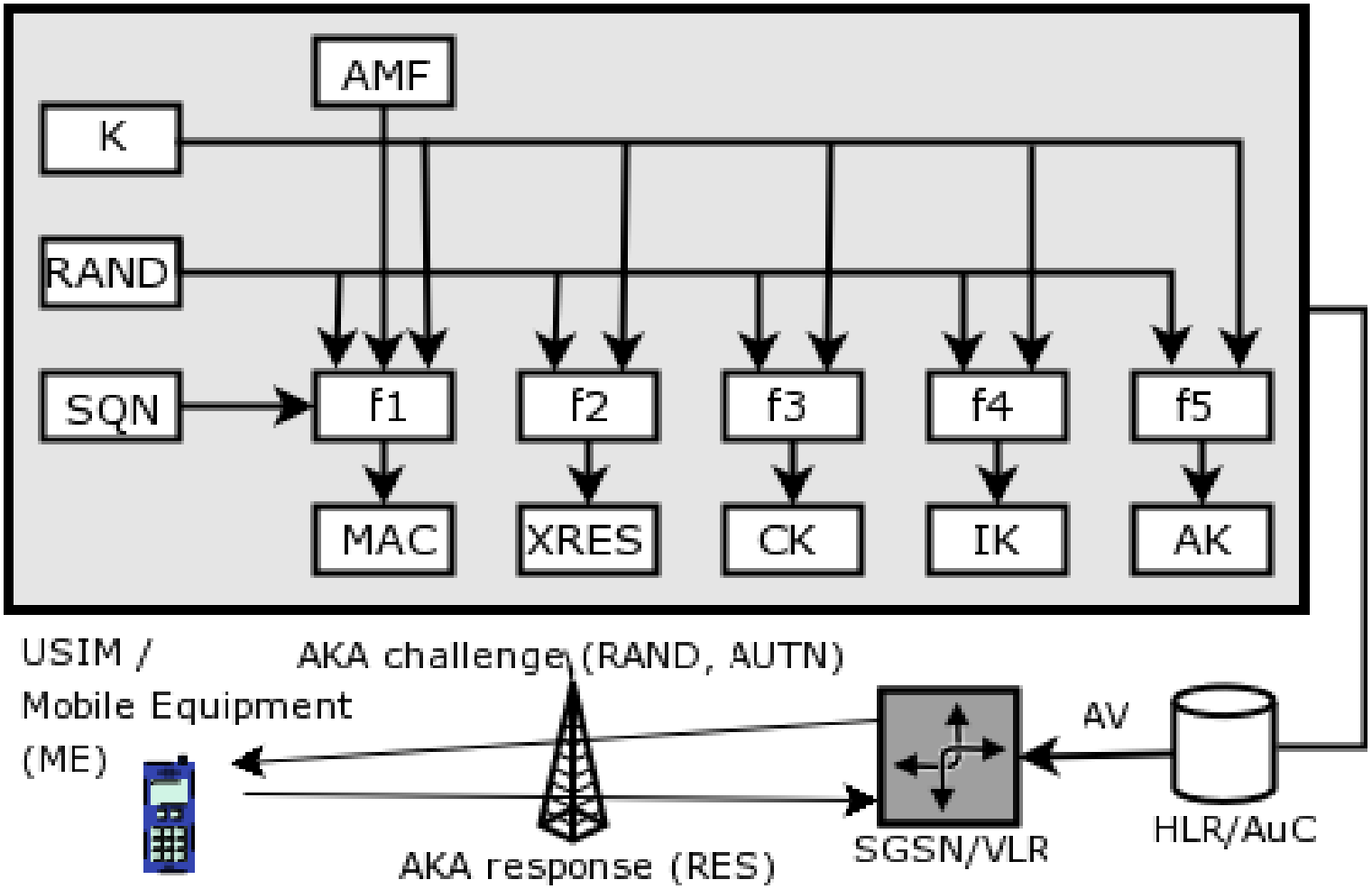
# Security and Authentication



- Security in GSM is weak by our todays standards, mostly broken and only one way (client-to-network auth)
- Authentication in UMTS
  - Basis is a common secret key K, which is only known by the USIM (User Services Identity Module) in the UE and by the HLR/AuC of the provider
  - The VLR or SGSN which should authenticate the user requests from the HLR/AuC 1..n AV(Auth Vectors)
  - Each AV is a 5-tupel consisting of
    - RAND (random challenge) and XRES (expected response) for the user authentication
    - CK (cipher key) for protection of confidentiality, IK (integrity key) for protection of integrity, AUTN (auth token) for network authentication

# Security and Authentication





# Security and Authentication



- RAND and AUTN are sent to the UE/USIM, which checks AUTN and computes the response RES to the challenge RAND
- RES is sent to the VLR/SGSN which compares it to XRES

- Integrity and confidentiality
  - By request of MSC/VLR or SGSN the communication can be encrypted with CK or IK between UE and RNC
  - Encryption takes place on the RLC layer and prevents forgery of data and encryption

# Summary



- From 2G to 3G
- Architecture of UMTS
  - UE
  - UTRAN
  - CN
- UMTS Handover
- UMTS Security

# Test your understanding



- Any idea about Virtual Home Environment (VHE)??

- What type of handover will happen when a mobile handset switch between 2G and 3G?

# Reference




- Jochen H. Schller, “Mobile Communications”, Second Edition, Pearson Education, New Delhi, 2007.