Cellular Wireless Networks

3G Systems (part 1)

IMT-2000

3GPP Releases

UMTS

CDMA2000

EDGE

Outline

- Last Lectures
  - Bluetooth 4.0/5.0
    - Low Energy Radio/Baseband

- This Lecture
    - IMT2000
    - 3GPP Releases
    - UMTS
      - Releases
      - Architecture
      - Spreading and scrambling
      - Frame structure
      - Channels
      - Mobility Support

[Schiller 03], [HT 07], [Q 06]

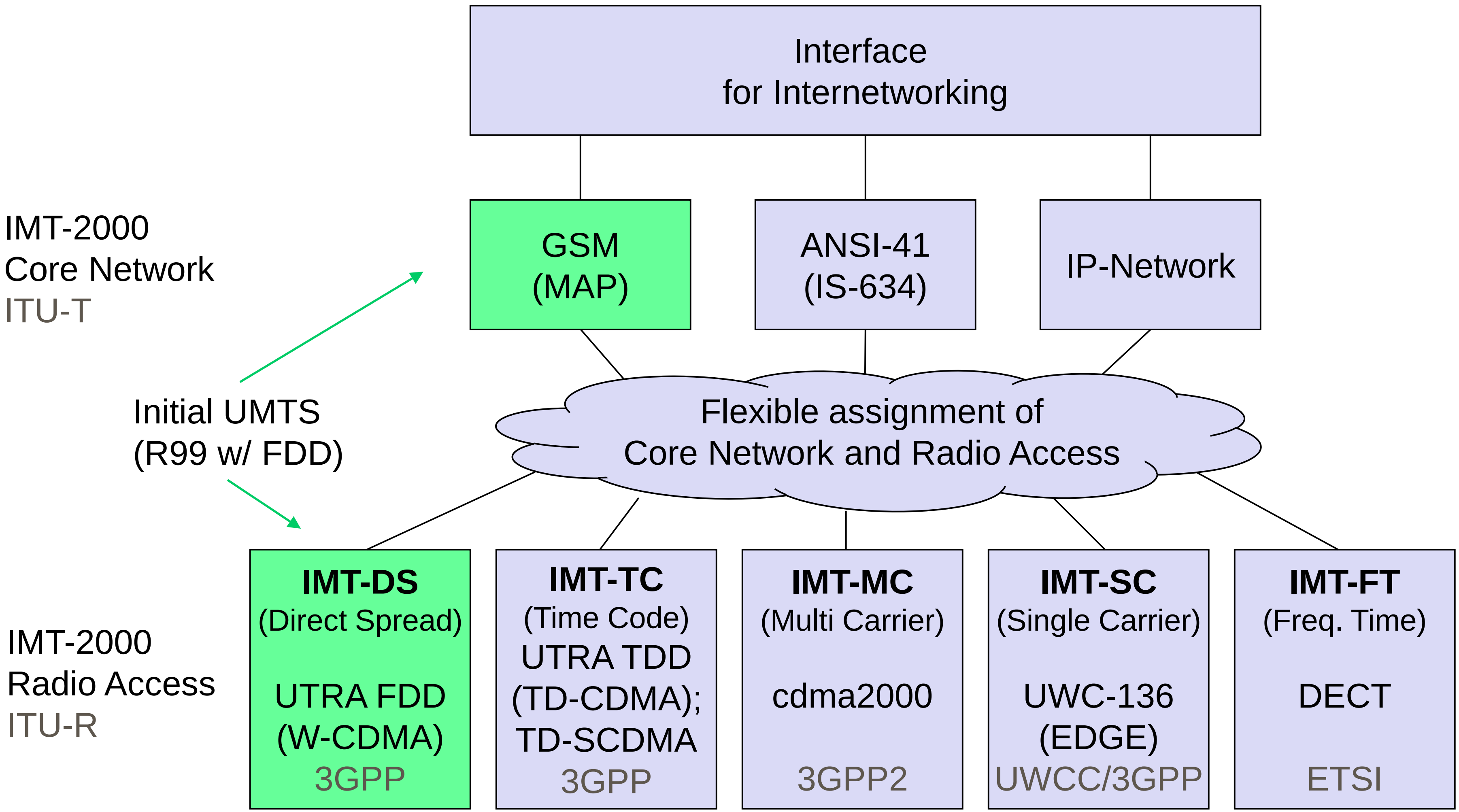
IMT-2000 [Schiller 03]

- How did 3G all start?
  - The International Telecommunication Union (ITU) made a request for proposals for Radio Transmission Technologies (RTT) for the international mobile telecommunications (IMT) 2000 program, formerly called F*uture Public Land Mobile Telecommunication System* (FPLMTS)
    - try to establish a common worldwide communication system, allowing terminal and user mobility, supporting the idea of universal personal telecommunication (UPT)
  - IMT-2000 includes different environments: indoor, vehicles, satellites and pedestrians
  - The World Radio Conference (WRC) 1992 identified 1885 - 2025 and 2110 - 2200 MHz as the frequency bands that should be available worldwide for the new IMT-2000 systems
    - Within these bands, two times 30 MHz have been reserved for mobile satellite services (MSS)

UMTS and IMT-2000 [Schiller 03]

- Proposals for IMT-2000 (International Mobile Telecommunications)
  - Universal Wireless Communication 136 (UWC-136)
    - from US, which extends IS-136
  - Cdma2000
    - based on IS-95 (US)
  - Wideband Packet CDMA (WP-CDMA)
    - which tries to align with UTRA
  - UMTS (Universal Mobile Telecommunications System)
    - from ETSI
- Basically, three big regions submitted proposals to the ITU:
  - ETSI for Europe
  - ARIB (Association of Radio Industries and Broadcasting) and TTC (Telecommunications Technology Council) for Japan
  - ANSI (American National Standards Institute) for the US

IMT-2000 family [Schiller 03]



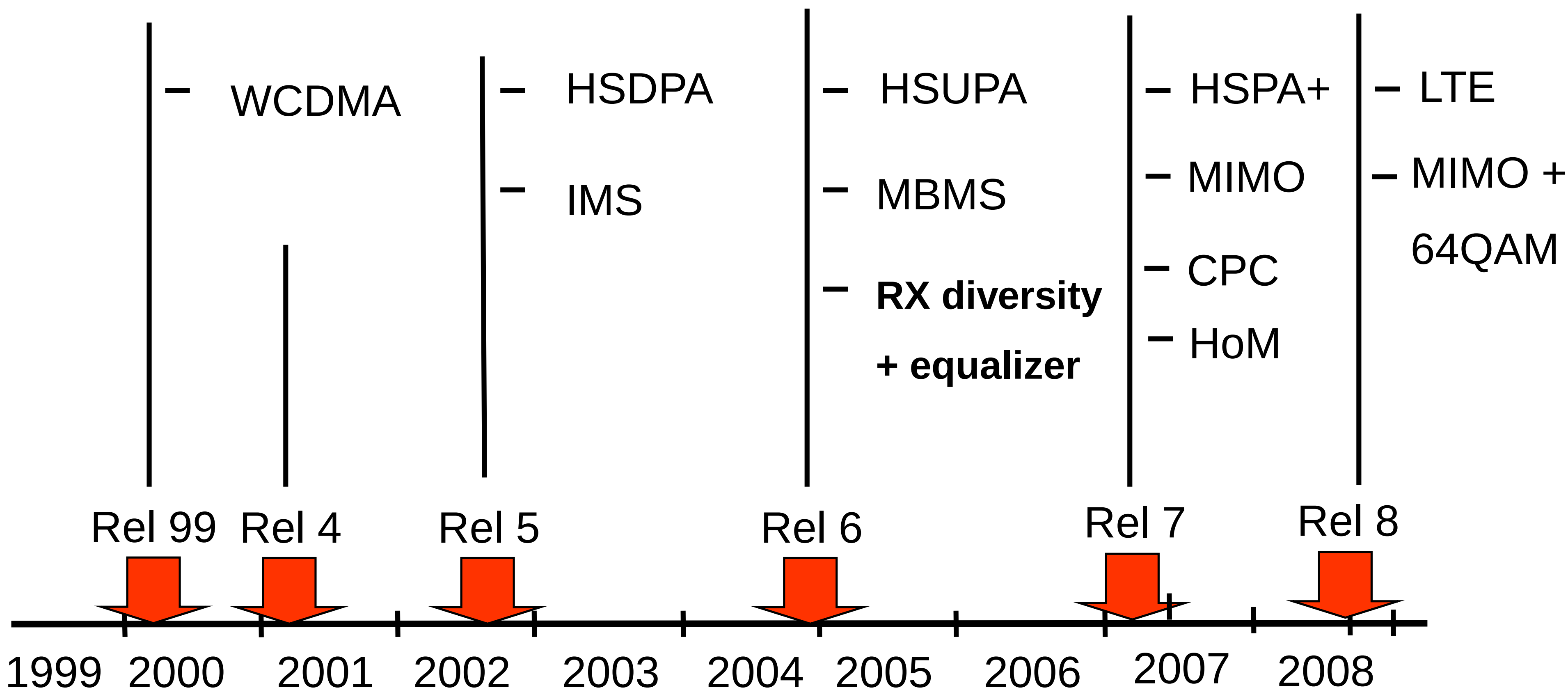
IMT-2000 family [Schiller 03]

- IMT-DS: direct spread technology
  - W-CDMA, specified for UTRA-FDD
  - used by all European providers and the Japanese NTT DoCoMo for 3G
  - in Japan this is promoted as FOMA (freedom of mobile multimedia access)
  - standardization of this technology takes place in 3GPP (Third generation partnership project)
    - 3GPP tends to be dominated by European and Japanese manufacturers and standardization bodies
- IMT-TC (time code)
  - UTRA-TDD system which uses time-division CDMA (TD-CDMA)
  - Chinese proposal, TD-synchronous CDMA (TD-SCDMA) was added
  - 3GPP fosters the development of this technology

IMT-2000 family [Schiller 03]

- IMT-MC: multi-carrier technology (cdma2000)
  - standardized by 3GPP2 (Third generation partnership project 2), it was formed shortly after 3GPP to represent the second main stream in 3G technology
  - 3GPP2 is dominated by the company Qualcomm and CDMA network operators
- IMT-SC: single carrier technology
  - The enhancement of the US TDMA systems (UWC-136)
  - integrated into the 3GPP efforts
  - This technology applies EDGE, among others, to enhance the 2G IS-136 standard
- IMT-FT: frequency time technology
  - an enhanced version of the cordless telephone standard DECT
  - ETSI is responsible for the standardization

3GPP releases



3GPP – UMTS releases

- Release 99 – deployed in 2001 (Japan), 2003 (Europe)
  - Major aspects covered here
  - downlink peak rate: in theory 2Mbps but in practice (384kbps) ~ 0.4Mbps ; uplink peak rate: 0.4Mbps
- Release 4: contained minor adjustments with respect to release 99
- Release 5 - deployed in 2005
  - inclusion of HSDPA (High Speed Downlink Packet Access)
  - downlink peak rate: 14Mbps ; uplink peak rate: 0.4Mbps
- Release 6 - deployed in 2007
  - HSDPA enhancements, HSUPA, IMS (IP Multimedia Subsystem), beam forming, WLAN integration, and IP transport, Multimedia Broadcast Multicast Service (MBMS), receive diversity + equalizer
  - downlink peak rate: 14Mbps ; uplink peak rate: 5.7Mbps
- Release 7- deployed in 2009
  - HSPA evolution (HSPA+), IP centric, VoIP, MIMO (Multiple Input Multiple Output), Higher order Modulation (HoM) (64QAM), and Continuous Packet Connectivity (CPC)
  - downlink peak rate: 28Mbps ; uplink peak rate: 11Mbps
  - Enhancements to conserve battery power and to make state changes quicker for a better browsing experience. Also referred to as Continued Packet Connectivity
  - HSUPA 16QAM for a faster uplink
  - Extended Cell Range

3GPP Releases (2)

- Release 8 (last freeze December 2008)
  - New radio system (LTE) based on OFDM, (the LTE baseline release)
  - Simultaneous use of 64QAM and MIMO on a single carrier
    - downlink peak rate: LTE 160Mbps, HSPA 42Mbps ; uplink peak rate: LTE 50Mbps
    - Coupled with improvements in the radio access network for continuous packet connectivity, HSPA+ will allow Uplink speeds of 11Mbps and Downlink speeds of 42Mbps within the Release 8 time frame.
  - Definition of Dual Carrier HSDPA - or Dual cell, specifying carrier aggregation for increased spectrum efficiency and load balancing across the carriers.
  - Single Radio Voice Call Continuity to hand-over voice calls from a packet to a circuit switched bearer
  - Femtocell definition (Home NodeBs)
  - ICE (In Case of Emergency) information storage on the SIM card and retrieval in a standardized way to help first responders to contact your family and friends in case something has happened to you.

- Release 9 (last freeze December 2009)
  - This added further enhancements to the SAE as well as allowing for WiMax and LTE/UMTS interoperability.
  - Separate dual carriers to simultaneously transmit downlink data in the 900 and 2100 MHz band.
  - Dual carrier in the uplink
  - Inclusion of the European Digital Dividend band

3GPP Releases (3)

- Release 10 (last freeze March 2011)
  - This release of the 3GPP standard detailed the 4G LTE Advanced technology.
  - up to 3Gbit/s downlink and 1.5Gbit/s uplink
  - carrier aggregation (CA), allowing the combination of up to five separate carriers to enable bandwidths up to 100MHz
  - higher order MIMO antenna configurations up to 8×8 downlink and 4×4 uplink
  - relay nodes to support Heterogeneous Networks (“HetNets”) containing a wide variety of cell sizes
  - enhanced inter-cell interference coordination (eICIC) to improve performance towards the edge of cells.

- Release 11 – (last freeze 2013)
  - Release 11 will build on the platform of Release 10 with a number of refinements to existing capabilities, including:
  - enhancements to Carrier Aggregation, MIMO, relay nodes and eICIC
  - introduction of new frequency bands
  - coordinated multipoint transmission and reception to enable simultaneous communication with multiple cells
  - advanced receivers.

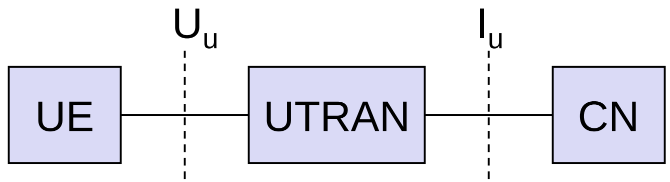
- Release 12 – (last freeze 2014)
  - enhanced small cells for LTE, introducing a number of features to improve the support of HetNets
  - inter-site carrier aggregation, to mix and match the capabilities and backhaul of adjacent cells
  - new antenna techniques and advanced receivers to maximise the potential of large cells
  - interworking between LTE and WiFi or HSPDA
  - further developments of previous technologies

Universal Mobile Telecommunications System - UMTS

- UTRA (Universal Terrestrial Radio Access)
- UMTS should
  - Provide several bearer services, real-time and non real time services, circuit and packet switched transmission, and many different data rates
  - Handover should be possible between UMTS cells, but also between UMTS and GSM or satellite networks
  - It should be compatible with GSM, ATM, IP, and ISDN-based networks
  - Provide a variable division of uplink and down- link data rates
  - Initial key requirements
    - min. 144 kbit/s rural (goal: 384 kbit/s), max. speed 500km/h
    - min. 384 kbit/s suburban (goal: 512 kbit/s), max. speed 120km/h
    - up to 2 Mbit/s urban, max. speed 10km/h (walking)

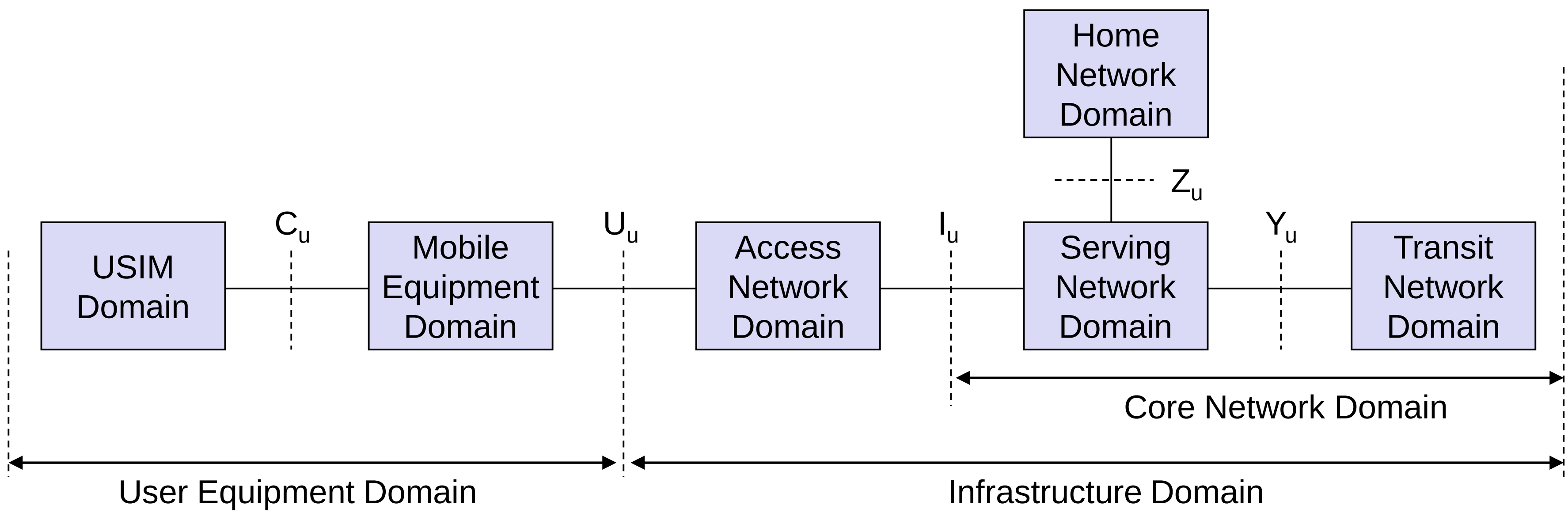
UMTS Architecture - Release 99 [Schiller 03]

- UTRAN (Universal Terrestrial Radio Access Network)
  - Cell level mobility
  - Comprises several Radio Network Subsystems (RNS)
    - functions include radio channel ciphering and deciphering, handover control, radio resource management, etc.
- UE (User Equipment)
- CN (Core Network)
  - Inter system handover
  - Gateways to other networks
  - Location management if there is no dedicated connection between UE and UTRAN



UMTS domains and interfaces [Schiller 03]

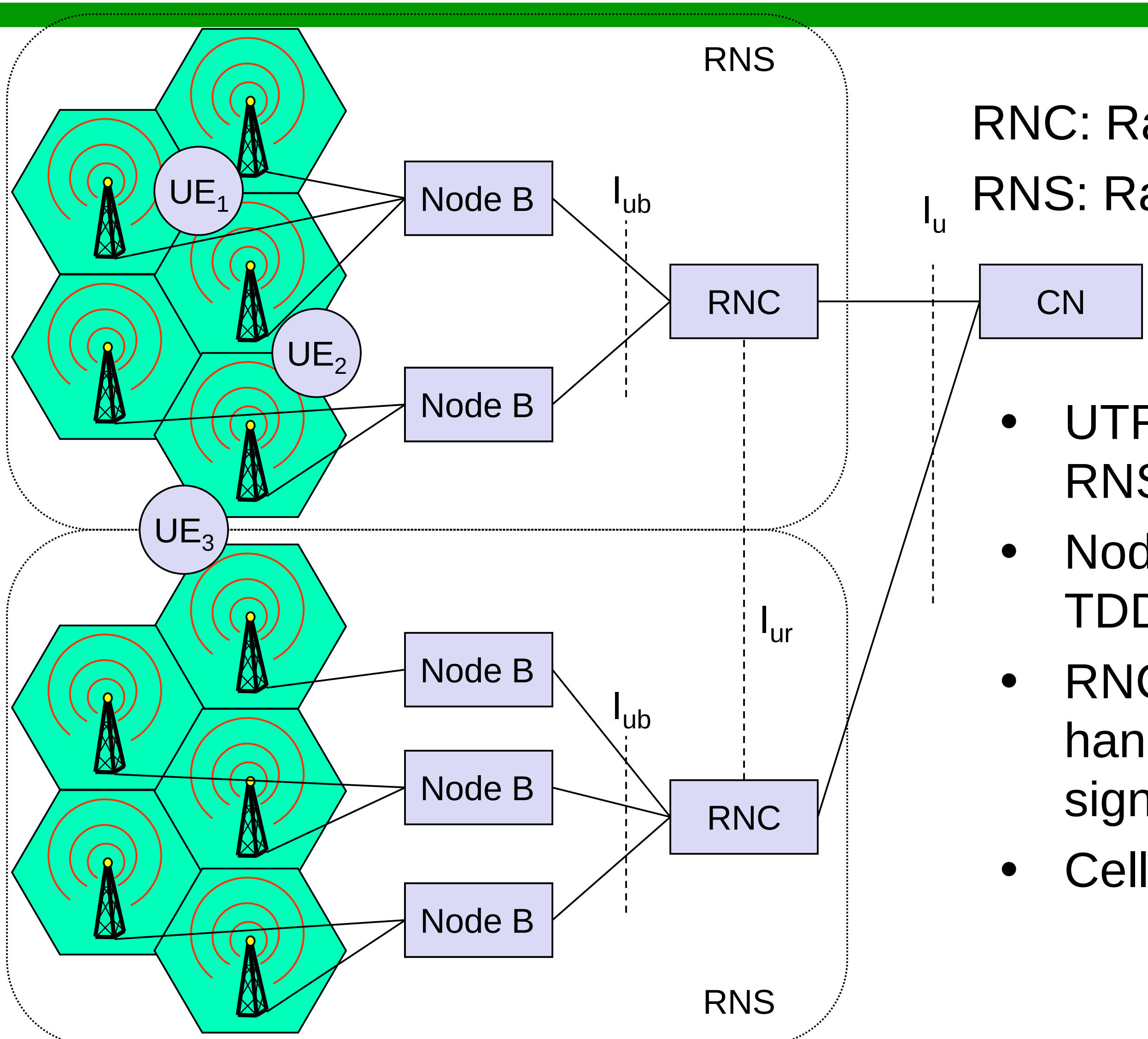
- User Equipment Domain
  - Assigned to a single user in order to access UMTS services
- Infrastructure Domain
  - Shared among all users
  - Offers UMTS services to all accepted users



UMTS domains and interfaces [Schiller 03]

- Universal Subscriber Identity Module (USIM) Domain
  - Functions for encryption, authentication and user related data
  - 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 (contains the RANs)
- Core Network Domain
  - Serving Network Domain
    - Network currently responsible for communication
    - Functions used by a user to access UMTS services
  - Home Network Domain
    - Location and access network independent functions
    - Functions related to the home network
  - Transit network domain
    - May be necessary if the serving network cannot contact directly the home network

UTRAN architecture [Schiller 03]



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 signalling to the UE
- Cell offers FDD or TDD

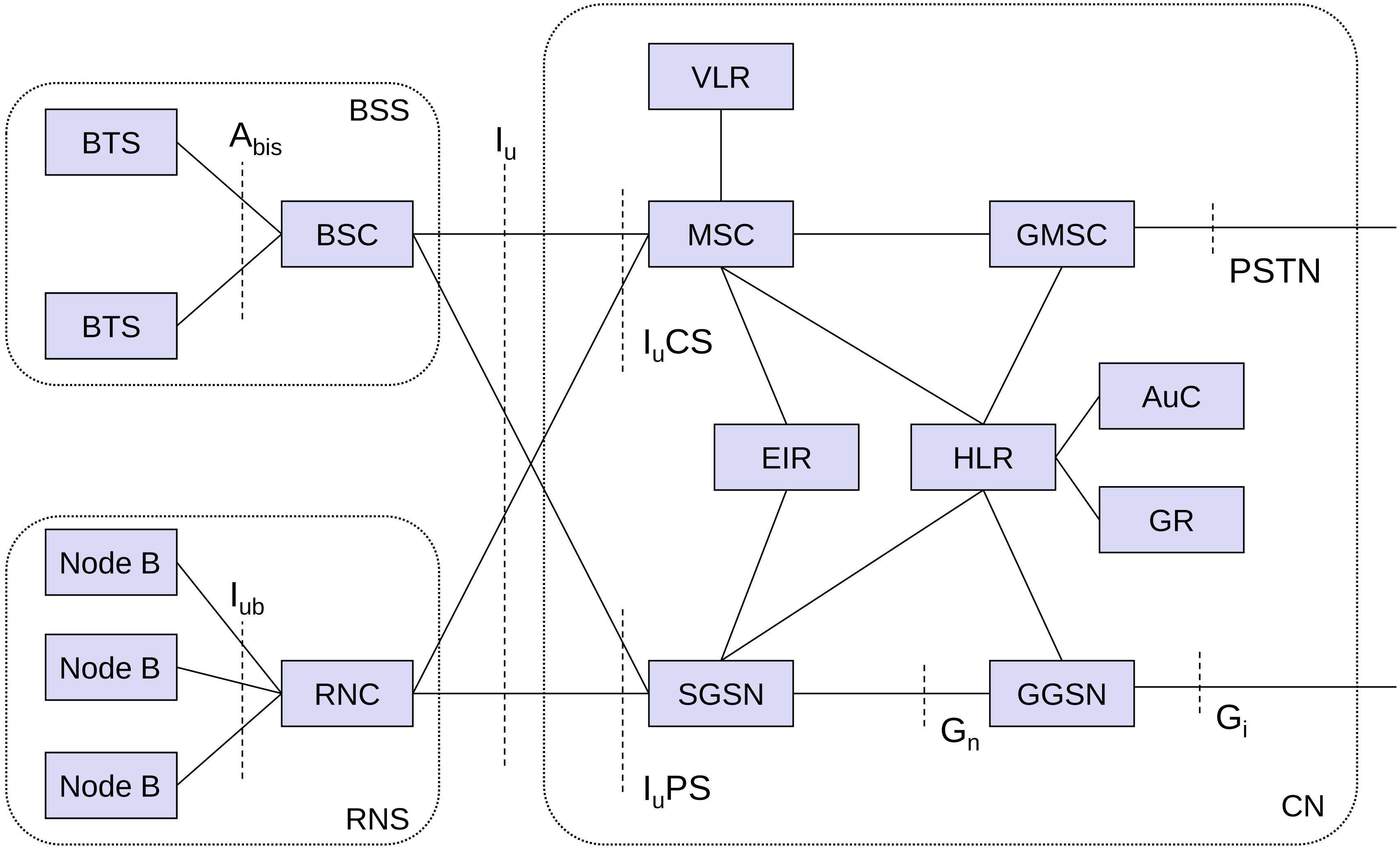
UTRAN – RNC functions [Schiller 03]

- **Call admission control**
  - Keep the interference below a certain level
  - Calculate the traffic within each cell and decide, if additional transmissions are acceptable or not
- **Congestion control**
  - RNC allocates bandwidth to each station in a cyclic fashion and must consider the QoS requirements.
- **Encryption/decryption**
- **ATM switching and multiplexing, protocol conversion**
- **Radio resource control**
  - Interference and load measurements
  - The priorities of different connections have to be obeyed.
- **Radio bearer setup and release**
- **Code allocation**
  - The CDMA codes used by a UE are selected by the RNC
- **Power control**
  - The RNC only performs a the outer loop power control
- **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**
  - Provide to network operators information regarding the current load, current traffic, error states etc.

Node B functions

- **Each node B** can control several antennas creating one or more cells or sectors
- Important functions
  - Main function is to perform the air interface layer 1 (L1) processing:
    - Channel coding and interleaving
    - Rate adaptation spreading, modulation etc.
  - Perform inner loop power control (faster closed loop control) to mitigate near-far effects
  - Measure connection quality and signal strength
  - Support softer handover which takes place between different antennas of the same node B

Core network: architecture [Schiller 03]



Core network [Schiller 03]

- 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_uCS
- Packet Switched Domain (PSD)
  - GPRS components (SGSN, GGSN)
  - I_uPS

- Release 99 uses the GSM/GPRS core network
  - Helped to save money in the initial phase
  - Allowed faster deployment
  - Not as flexible as releases 5 and 6

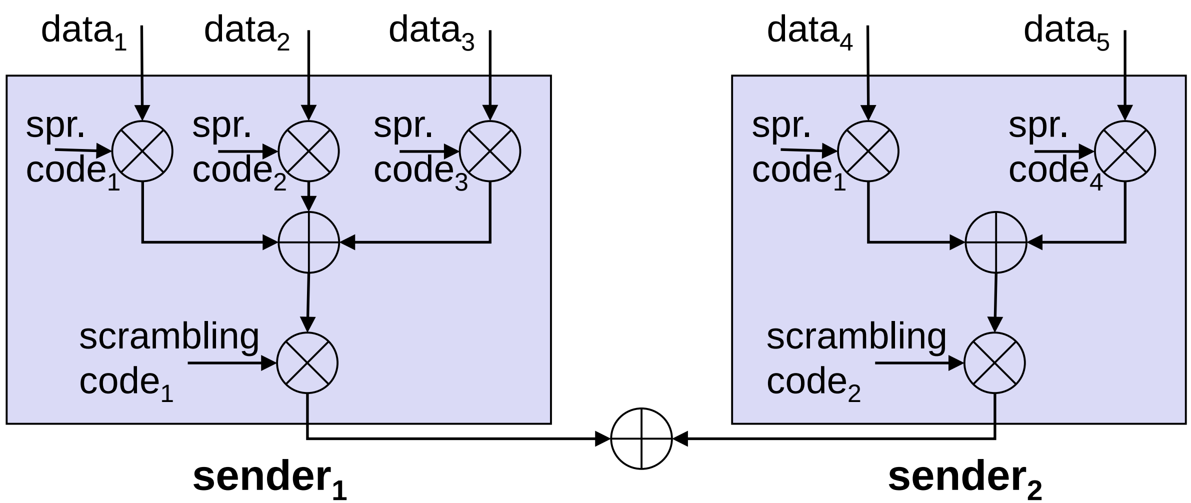
Spreading and scrambling of user data [Schiller 03]

- 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 synchronisation not necessary as the scrambling codes stay quasi-orthogonal

Spreading and scrambling of user data [Schiller 03]

- The first step is spreading of user data
  - using orthogonal spreading codes to separate the different data streams of a sender
  - UMTS uses so-called Orthogonal Variable Spreading Factor (OVSF) codes
- The spreading codes in different senders can be the same
  - Using different spreading codes in all senders within a cell would require a lot of management and would increase the complexity
- After spreading all chip streams are added and scrambled
  - Scrambling does not spread the chip sequence any further
  - The scrambling code is unique for each sender and separates all senders
- After scrambling, the signals of different senders are quasi orthogonal

Spreading and scrambling of user data [Schiller 03]

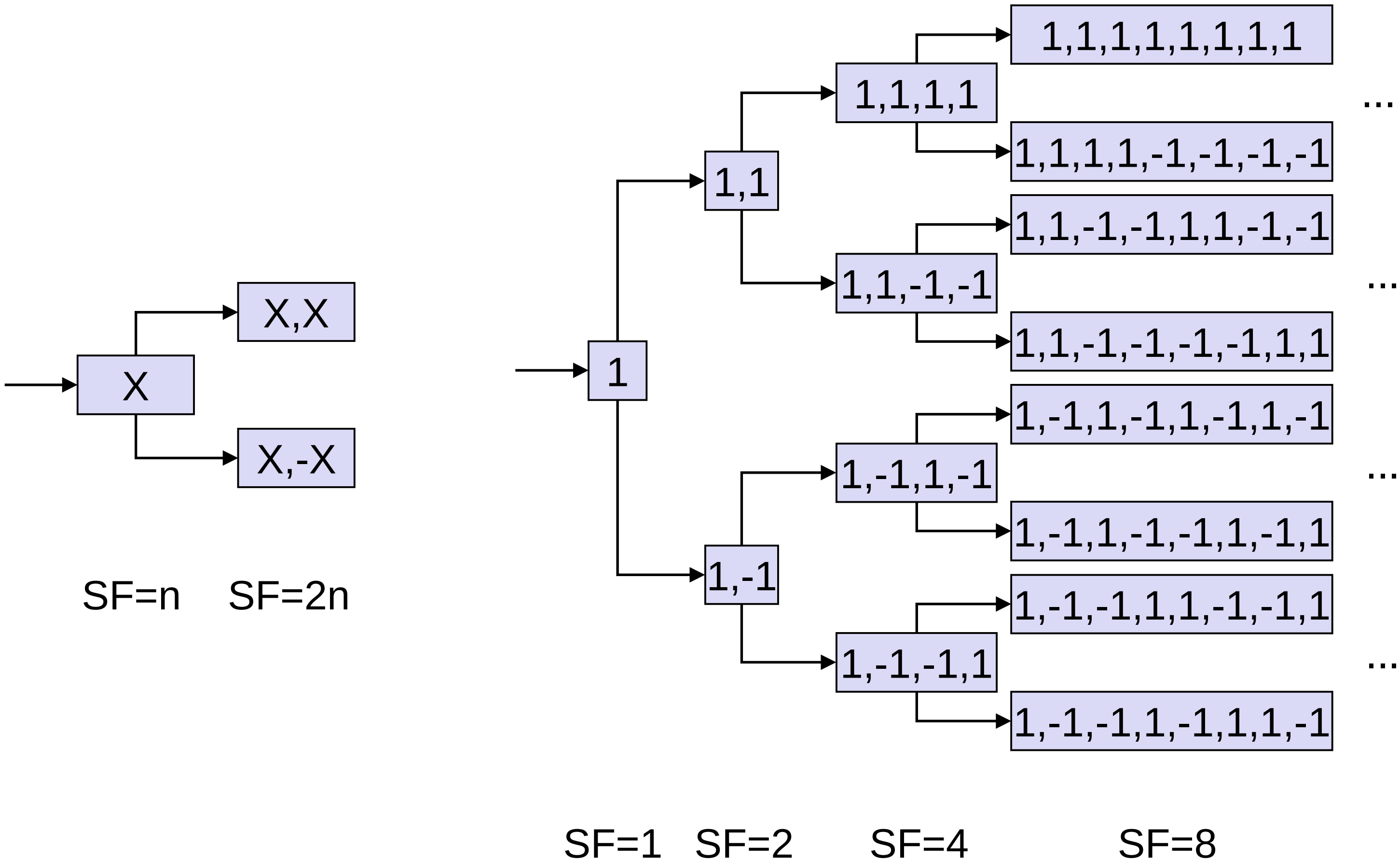


OVSF coding [Schiller 03]

- The basic idea of OVSF codes:
  - They are generated by doubling a chipping sequence X with and without flipping the sign of the chips (see figure next slide)
  - Doubling the chipping sequence also results in spreading a bit twice as much as before
  - Next slide shows the generation of orthogonal codes with different spreading factors

- Two codes are orthogonal as long as one code is never a part of the other code
  - Looking at the coding tree, orthogonality is guaranteed if one code has not been generated based on another
  - For example, if a sender uses the code (1,-1), it is not allowed to use any of the codes located in the sub-trees generated out of (1,-1)

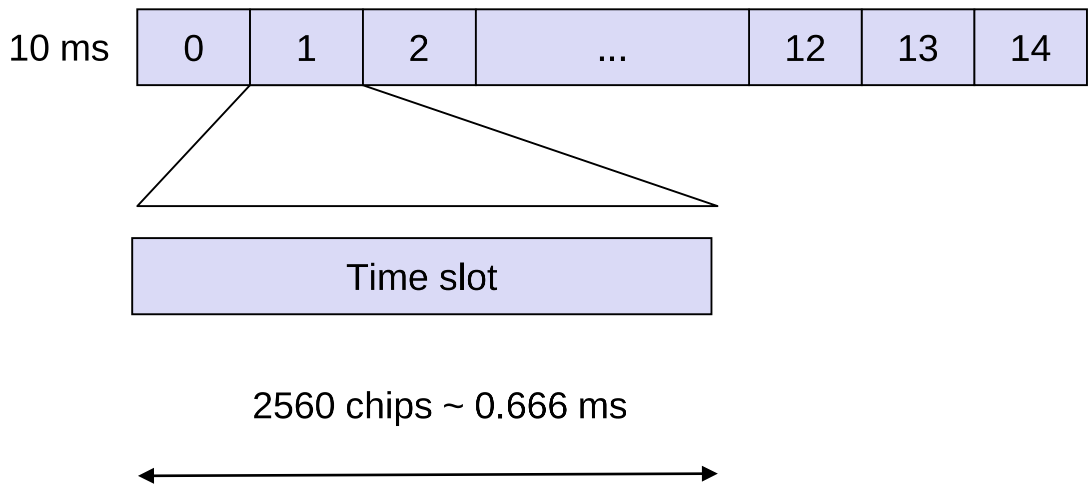
OVSF coding [Schiller 03]



UMTS FDD frame structure [Schiller 03]

- **W-CDMA**
  - 1920-1980 MHz uplink, 2110-2170 MHz downlink
  - chipping rate: 3.840 Mchip/s, radio frame comprising 15 time slots
    - A radio frame consists of 38,400 chips and has a duration of 10 ms
  - Time slots in W-CDMA are not used for user separation but to support periodic functions
    - Each time slot consists of 2,560 chips, which roughly equals 666.6 micro seconds
  - The occupied bandwidth per W-CDMA channel is 4.4 to 5 MHz
    - avoid interference between channels of different operators
  - soft handover, QPSK, complex power control - pc (1500 pc cycles/s)
  - UTRA FDD requires at least twice as many base stations as GSM
    - Common cell diameters of 500 m, coverage for cities and highways only
    - countryside will have to rely on GSM/GPRS for some years to come

UMTS FDD frame structure [Schiller 03]



UMTS Logical Channels [HT 07]

- Dedicated Transport Channel
  - It carries all the information intended for the given user coming from layers above the physical layer, including data for the actual service as well as higher layer control information
    - it carries both the service data, such as speech frames, and higher layer control information, such as handover commands or measurement reports from the terminal.
    - The content of the information carried on the DCH is not visible to the physical layer
  - It supports
    - fast power control
    - fast data rate change on a frame-by-frame basis
    - transmission to a certain part of the cell or sector with varying antenna weights with adaptive antenna systems
    - soft handover

UMTS Logical Channels [HT 07]

- Common Transport Channels
  - Broadcast channel (BCH)
    - transmit information specific to the UTRA network or for a given cell
      - E.g. available random access codes and access slots in the cell
    - transmitted with relatively high power in order to reach all the users within the intended coverage area
    - low and fixed data rate
  - Forward Access Channel (FACH)
    - Control information to terminal and packet data to terminals known to be located in a given cell
      - It is used, for example, after a random access message has been received by the base station
    - There can be more than one FACH in a cell
      - One with low bit rate to be received by all the terminals in the cell
      - Additional FACH channels can have a higher data rate
    - It does not use fast power control

UMTS Logical Channels [HT 07]

- Common Transport Channels (cont.)
  - Paging Channel (PCH)
    - It carries data relevant to the paging procedure
    - The network transmits the paging message to those cells belonging to the location area that the terminal is expected to be in
    - The terminals must be able to receive the paging information in the whole cell area
    - Influences terminal's power consumption in the standby mode
  - Random Access Channel (RACH)
    - Access and also small amounts of packet data
    - It must be heard from the whole desired cell coverage area, which also means that practical data rates have to be rather low, at least for the initial system access and other control procedures

UMTS Logical Channels [HT 07]

- Common Transport Channels (cont.)
  - Uplink Common Packet Channel (CPCH)
    - Extension to RACH intended to carry packet-based user data
    - Never implemented by network operators, taken out from specs in R5
  - Downlink Shared Channel (DSCH)
    - Carries dedicated user data and/or control information, but it can be shared by several users
    - Similar to FACH, but uses fast power control and variable bit rate
    - In practice this logical channel was replaced by HSDPA, therefore it was taken out from specs in R5

UMTS Physical Channels [HT07]

- Transport channels are mapped into physical channels, for example, DCH is mapped to:
  - **Dedicated physical data channel (DPDCH):**
    - This channel conveys user or higher layer control information from DCH
    - spreading: UL: 4-256; DL:4-512
  - **Dedicated physical control channel (DPCCH):**
    - In each connection layer 1 needs exactly one DPCCH.
    - This channel conveys control data for the physical layer only and uses the constant spreading factor 256
- Main physical channels that only carry information relevant to physical layer procedures
  - Synchronisation Channel (SCH)
  - Common Pilot Channel (CPICH)

UMTS Physical Channels [HT07]

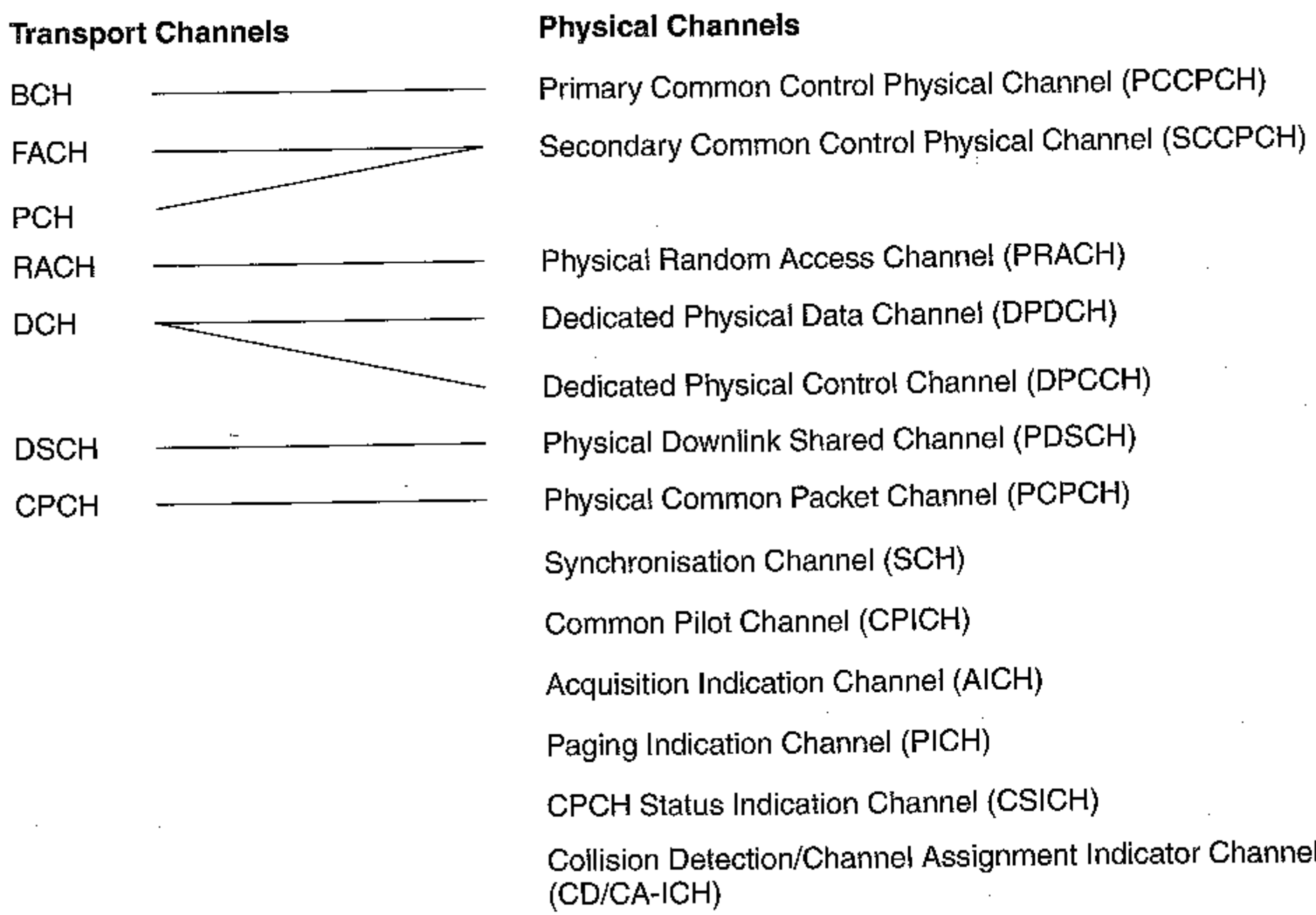
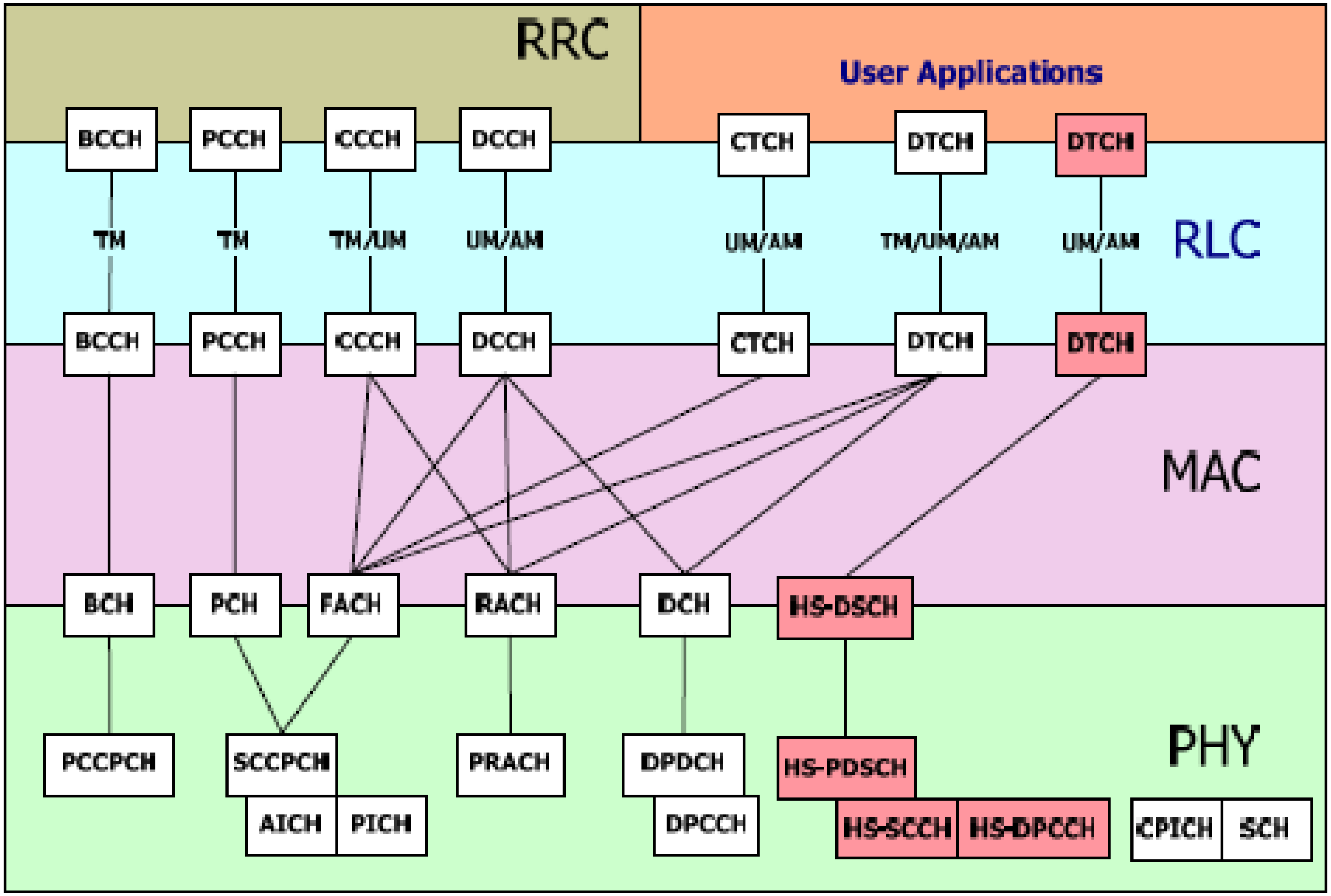


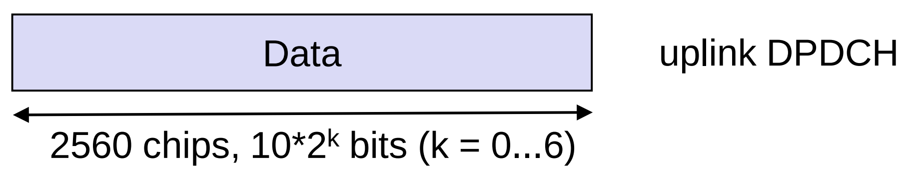
Figure 6.2. Transport-channel to physical-channel mapping

UMTS Logical and Physical Channels [Q 06]



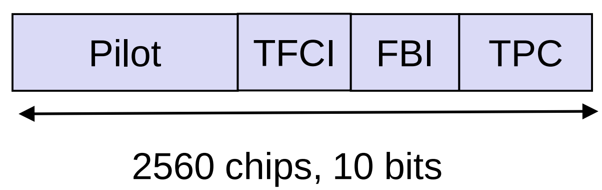
UMTS Physical Channels [Schiller 03]

- Dedicated physical data channel (DPDCH):
  - The spreading factor of this channel can vary: 960 kbit/s (spreading factor 4, 640 bits per slot, 15 slots per frame, 100 frames per second), 480, 240, 120, 60, 30, and 15 kbit/s (SF=256)
  - problems of OVSF: only certain multiples of the basic data rate of 15 kbit/s can be used
    - example, 250 kbit/s are needed the device has to choose 480 kbit/s
  - In each connection in layer 1 it can have between zero and six DPDCHs
    - a theoretical maximum data rate of 5,740 kbit/s (R99 describes UEs with a maximum of 1,920 kbit/s only)
    - Table 4.7 shows typical user data rates together with the required data rates on the physical channels



UMTS Physical Channels [Schiller 03]

- Dedicated physical control channel (DPCCH):
  - The pilot bits are used for channel estimation
  - Spreading factor 256
  - The transport format combination identifier (TFCI) specifies the channels transported within the DPDCHs
    - The DPDCH data rate may vary on a frame-by-frame basis. Typically with a variable rate service the DPDCH data rate is informed on the DPCCH. The DPCCH is transmitted continuously and rate information is sent with the Transport Format Combination Indicator TFCI
  - Signaling for fast closed loop power control in a soft handover is supported by the feedback information field (FBI)
  - The last field, transmit power control (TPC) is used for controlling the transmission power of a sender
  - Power control is performed in each slot, thus 1,500 power control cycles are available per second



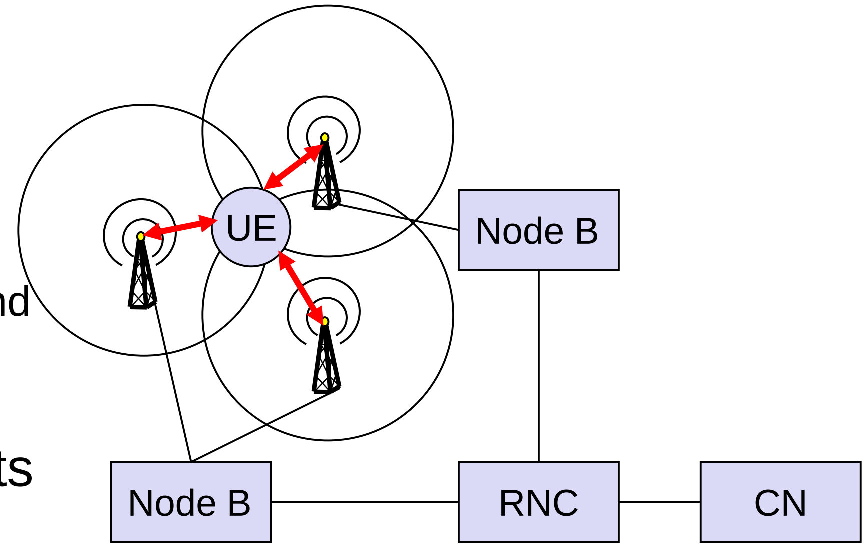
Medium Access Control [Schiller 03]

- Medium access on the uplink
  - A physical random access channel (PRACH) has 15 random access slots within 20 ms
  - 16 different access preambles
  - Using slotted Aloha, a UE can access an access slot by sending a preamble.
  - The UE starts with the lowest available transmission power to avoid interfering with other stations
  - If no positive acknowledgement is received, the UE tries another slot and another preamble with the next higher power level (power ramping)
  - The number of available access slots is transmitted via a broadcast channel

Mobility Support: Hard Handover

- Same as in GSM and other TDMA/FDMA systems
- Switching between different antennas or different systems is performed at a certain point in time
- UTRA TDD can only use this type
- All inter system handovers are hard handovers in UMTS
- To enable a UE to listen into GSM or other frequency bands, UMTS specifies a compressed mode transmission for UTRA FDD
  – During this mode a UE stops all transmission

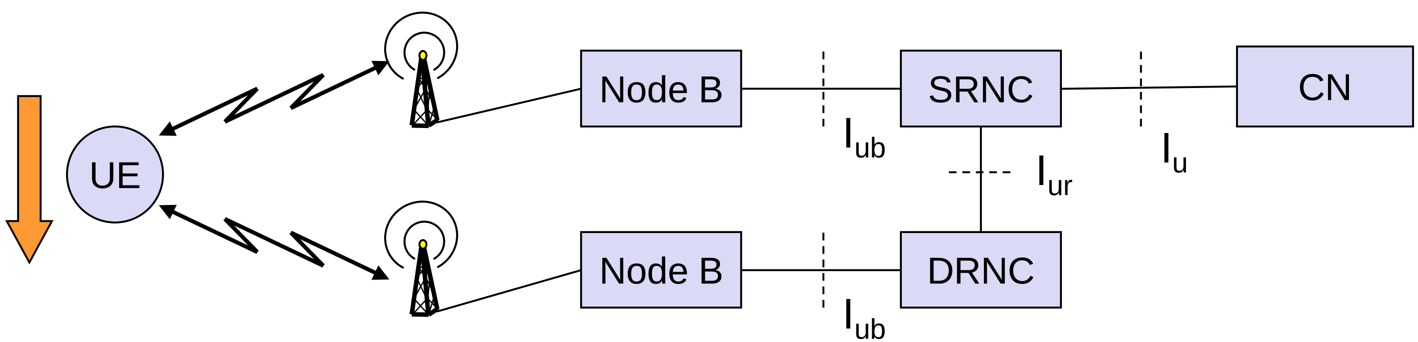
Mobility Support: Soft Handover [Schiller 03]



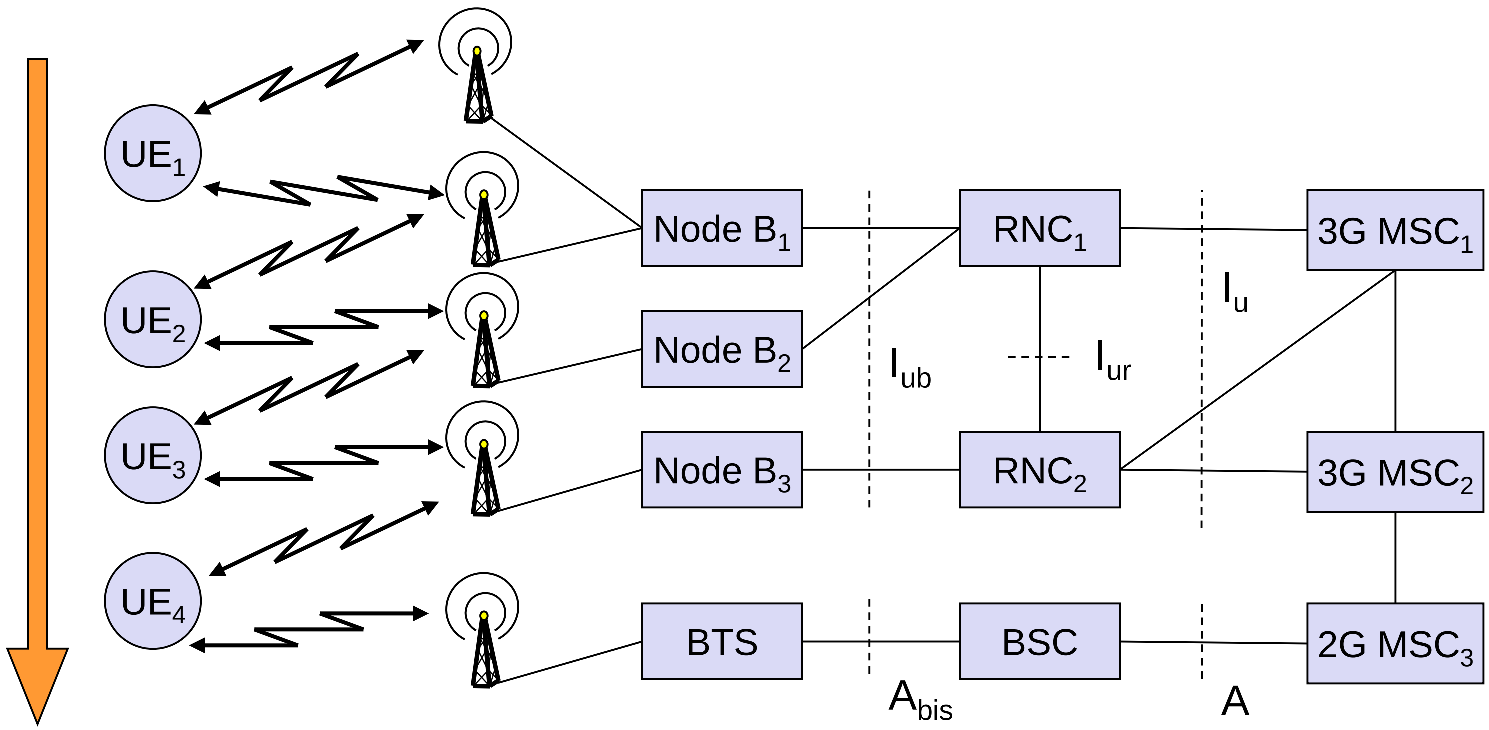
- Only available in the FDD mode
- UE can receive signals from up to three different antennas, which may belong to different node Bs.
  - Towards the UE the RNC splits the data stream and forwards it to the node Bs
  - The UE combines the received data again.
- In the other direction, the UE simply sends its data which is then received by all node Bs involved
  - The RNC combines the data streams received from the node Bs
- As soft handover is not supported by the CN, all mechanisms related to soft handover must be located within UTRAN

Mobility Support: handover [Schiller 03]

- RNC controlling the connection is called SRNC (Serving RNC)
- RNC offering additional resources (e.g., for soft handover) is called Drift RNC (DRNC)
- End-to-end connections between UE and CN only via I_u at the SRNS
  - Change of SRNC requires change of I_u
  - Initiated by the SRNC
  - Controlled by the RNC and CN



Example handover types in UMTS/GSM [Schiller 03]



Example handover types in UMTS/GSM [Schiller 03]

- **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
  - The internal inter-RNC handover is not visible for the CN
    - RNC1 can act as SRNC, RNC2 will be the DRNC
    - The CN will communicate via the same interface Iu all the time
  - As soon as a relocation of the interface Iu takes place (relocation of the controlling RNC), the handover is called an external inter-RNC handover
  - Communication is still handled by the same MSC1, but the external handover is now a hard handover

Example handover types in UMTS/GSM [Schiller 03]

- **Inter-MSC**
  - It could be also the case that MSC2 takes over and performs a hard handover of the connection
- **Inter-system**
  - UE4 moves from a 3G UMTS network into a 2G GSM net work. This hard handover is important for real life usability of the system between 3G and 2G networks

References

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Class Quiz

- What is the UMTS architecture?
- What is the function of RNC?
- What is the spreading code in UMTS?

Further information slides

Common Pilot Channel (CPICH)

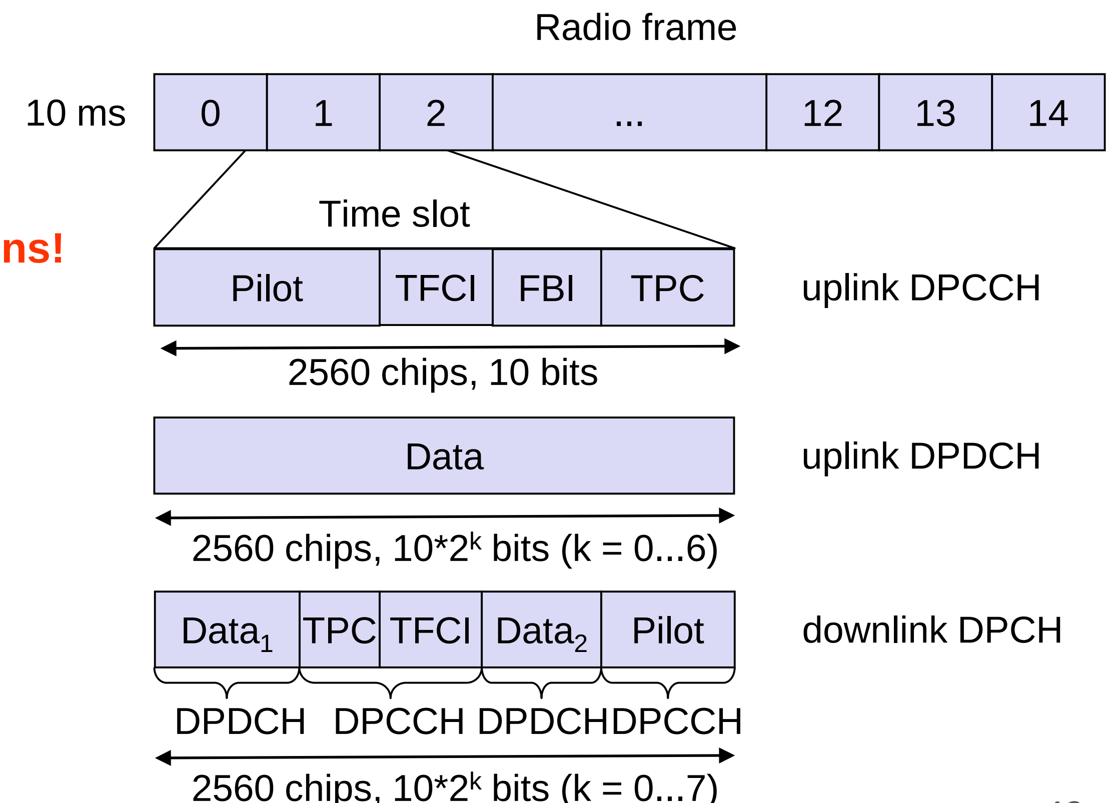
- It is scrambled with the cell specific primary scrambling code
- Function: aid the channel estimation at the terminal
- UTRA has two types of common pilot channel, primary and secondary:
  - The primary scrambling code with a fixed channelisation code allocation and there is only one such channel for a cell or sector
    - Important for handover and cell selection/reselection, by adjusting the CPICH power level, the cell load can be balanced between different cells
  - The secondary CPICH may have any channelisation code of length 256 and may be under a secondary scrambling code as well
    - The typical usage would be operations with narrow antenna beams intended for service provision at specific ‘hot spots’ or places with high traffic density
- The CPICH does not carry any higher layer information, neither is there any transport channel mapped to it
- The CPICH uses a fixed spreading factor of 256

Synchronisation Channel (SCH)

- It is needed for the cell search
- It consists of two channels, the primary and secondary synchronisation channels
- The primary uses a 256-chip spreading sequence identical in every cell
- The secondary uses sequences with different code word combination possibilities representing different code groups
  - Once the terminal has identified the secondary synchronisation channel, it has obtained frame and slot synchronisation as well as information on the group the cell belongs to
  - Search is performed at the initial search upon terminal power on or when entering a coverage area
- No transport channel is mapped on the SCH
- The code words are transmitted for cell search purposes only
- It is time multiplexed with the Primary Common Control Physical Channel
- The Primary and Secondary SCH are sent in parallel

UMTS FDD frame structure [Schiller 03]

- Dedicated physical channel (DPCH):
  - The downlink time multiplexes control and user data
  - Spreading factors between 4 and 512 are available
  - many different burst formats (17 altogether) have been defined which differ in the size of the field



Slot structure NOT for user separation but synchronisation for periodic functions!

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

Initialisation [Schiller 03]

- UE Initialisation procedure
  - Primary synchronisation: A UE has to synchronise with the help of a 256 chip primary synchronisation code. This code is the same for all cells and helps to synchronise with the time slot structure
  - Secondary synchronisation: UE receives a secondary synchronisation code which defines the group of scrambling codes used in this cell. The UE is now synchronised with the frame structure
  - Identification of the scrambling code: The UE tries all scrambling codes within the group of codes to find the right code with the help of a correlator
  - After that UE can receive all further data over a broadcast channel