Cellular Networks
3rd Generation (3G)

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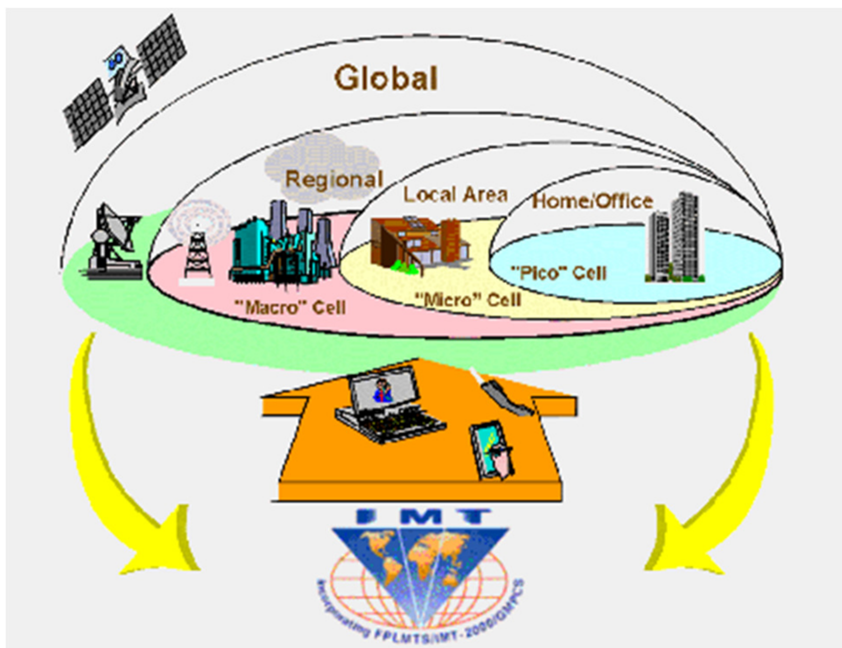
References

- Jeffrey Bannister, Paul Mather, Sebastian Cooper, "Convergence Technologies for 3G Networks- IP, UMTS, EGPRS and ATM" John Wiley and Sons 2004.

Early 3G Discussion

- Work on 3G mobile communication started in ITU by IMT-2000.
- International Mobile Telecommunications for the year 2000 is a worldwide set of requirements for a family of standards for the 3rd generation of mobile communications.
- Goal: evolve from 2G to higher data rates with minimum required changes.



IMT-2000 QoS Attributes

- Maximum bit rate
- Guaranteed bit rate
- Delivery order
- Maximum Service Data Unit (SDU) size
- SDU error ratio
- Residual BER
- Delivery of erroneous SDUs
- Transfer delay
- Traffic handling priority
- Allocation/Retention Priority

IMT-2000 QoS Characterizations

- Conversational Class
  - preserve time relation (variation) between information entities
  - transfer delay significantly lower and more stringent than round-trip delay of interactive traffic
- Streaming Class
  - preserve time relation (variation) between information entities of the stream
  - acceptable delay is much greater than the delay limits of human perception
- Interactive Class
  - request response pattern (low round trip delay)
  - preserve payload content (low BER)
- Background Class
  - destination is not expecting the data within a certain time
  - preserve payload content (low BER)

Focus of 3G Standard Efforts

- Standard organizations efforts are centered on how to harmonize the following key and interrelated issues:
  - Architecture of radio interface and fixed network
  - System evolution and backward compatibility
  - Accommodation of user migration and global roaming
  - Phased introduction of mobile services and capabilities for terminal mobility support

3G standardization starts

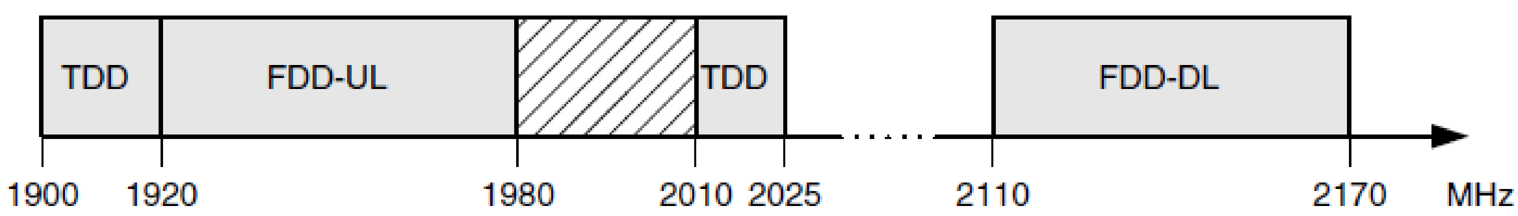
- In1998 the Third Generation Partnership Project (3GPP) was formed by standards-developing organizations from all regions of the world.
  - ARIB (Japan, NA), CCSA (China), ETSI (Europe), ATIS (USA), TTA (Korea) and TTC (Japan).
- A parallel partnership project called 3GPP2 was formed in 1999. It also develops 3G specifications, but for cdma2000, which is the 3G technology developed from the 2G CDMA-based standard IS-95.
  - ARIB, CCSA, TIA, TTA and TTC.

Major Standards

- Universal Mobile Telecommunications System (UMTS)
  - Also known as WCDMA
  - Developed by 3GPP
  - backward compatibility with GSM in terms of network protocols and interfaces.
- CDMA2000
  - Known as IS200, or 1xRTT
  - Developed by 3GPP2
  - Backward compatible with IS-95

UMTS FDD AND TDD

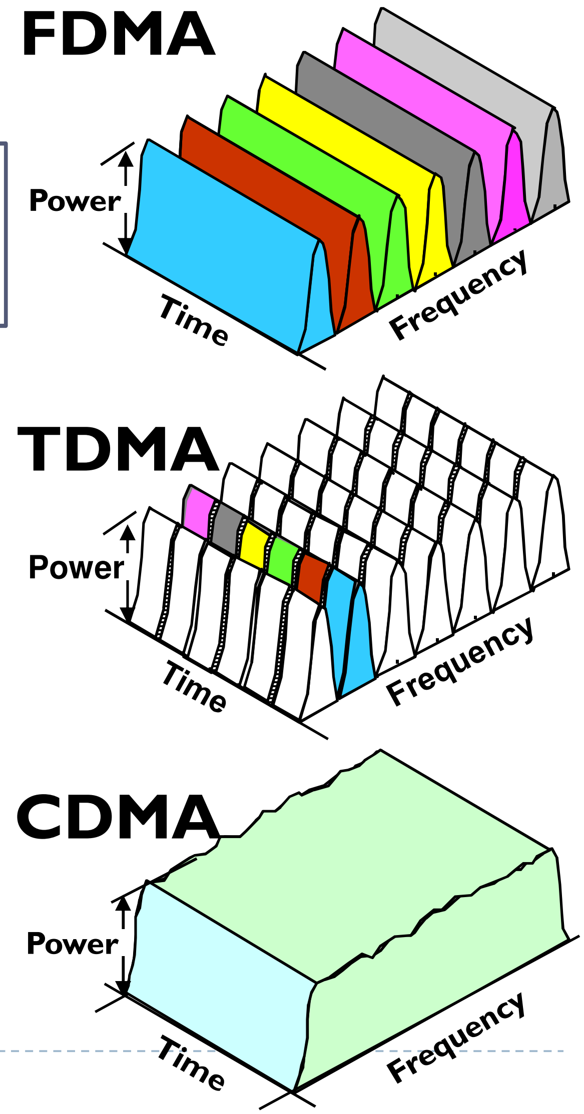
- Two radio technologies under UMTS umbrella
  - Frequency division duplexing (paired spectrum): separates traffic in the uplink and downlink by placing them at different channels.
  - Time division duplexing (unpaired spectrum): requires only one frequency channel, and uplink and downlink traffic are separated by sending them at different times.
- The TDD system does not really be considered as an independent network, but rather
  - as a supplement for an FDD system to provide hotspot coverage at higher data rates.
  - ideal for indoor coverage over small areas.



Wideband System

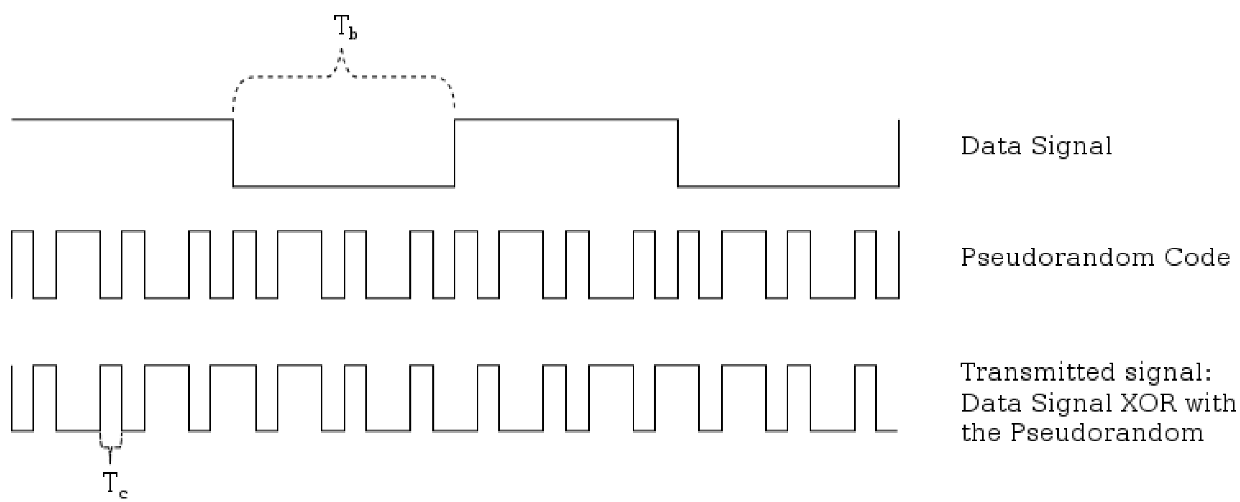
- The entire system bandwidth is made available to each user.
- Much larger than the information bandwidth.
- Spread spectrum (SS) systems
  - Direct sequence spread spectrum (DSSS): baseband signal is spread over a large bandwidth by a spreading code called chis.
  - Frequency hopping spread spectrum (FHSS): the binary pseudo-random noise (PN) code generator drives the frequency synthesizer to hop to one of the many available frequencies chosen by the PN sequence generator.

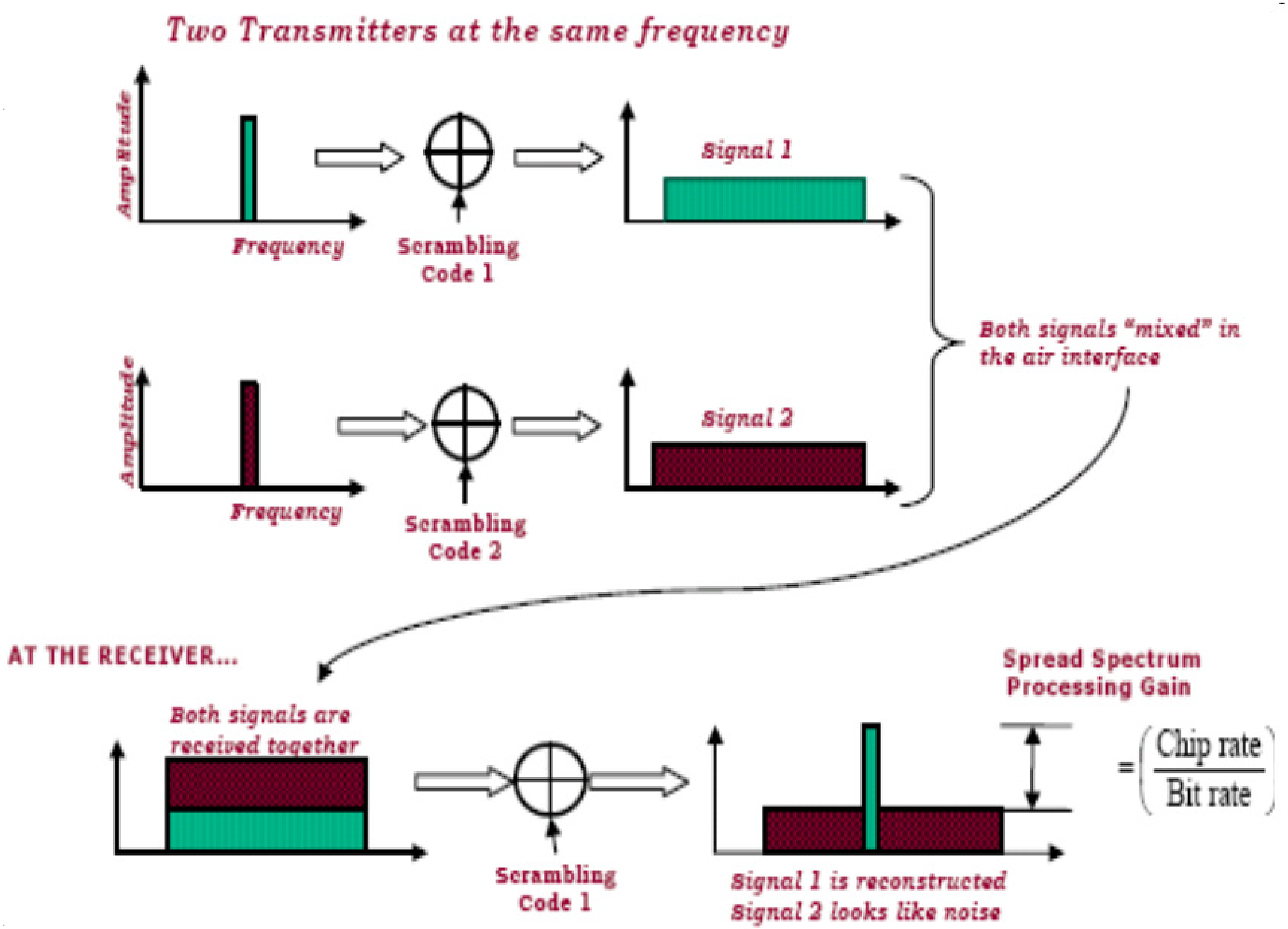
UMTS Choice



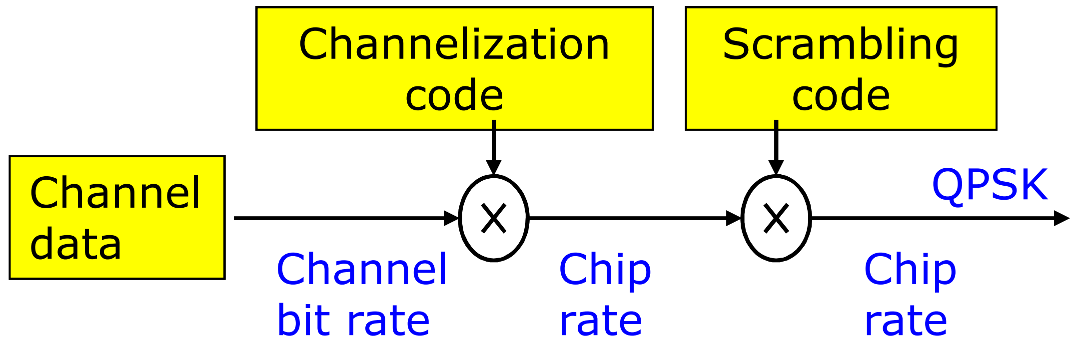
WCDMA System

- WCDMA is the radio interface for UMTS systems.
- Wide bandwidth, 3.84 Mcps (Mega chips per second)
  - Maps to 5 MHz due to pulse shaping and small guard bands between the carriers.
- Users share the same 5 MHz frequency band and time
  - UL and DL have separate 5 MHz frequency bands in FDD
  - Users are separated from each other with codes and thus frequency reuse factor is equal to 1




Two Transmitters at the same frequency
Amplitude
Frequency
Scrambling Code 1
Signal 1
Both signals "mixed" in the air interface
Amplitude
Frequency
Scrambling Code 2
Signal 2
AT THE RECEIVER...
Both signals are received together
Scrambling Code 1
Spread Spectrum Processing Gain
= (Chip rate / Bit rate)
Signal 1 is reconstructed
Signal 2 looks like noise

WCDMA System (cont.)



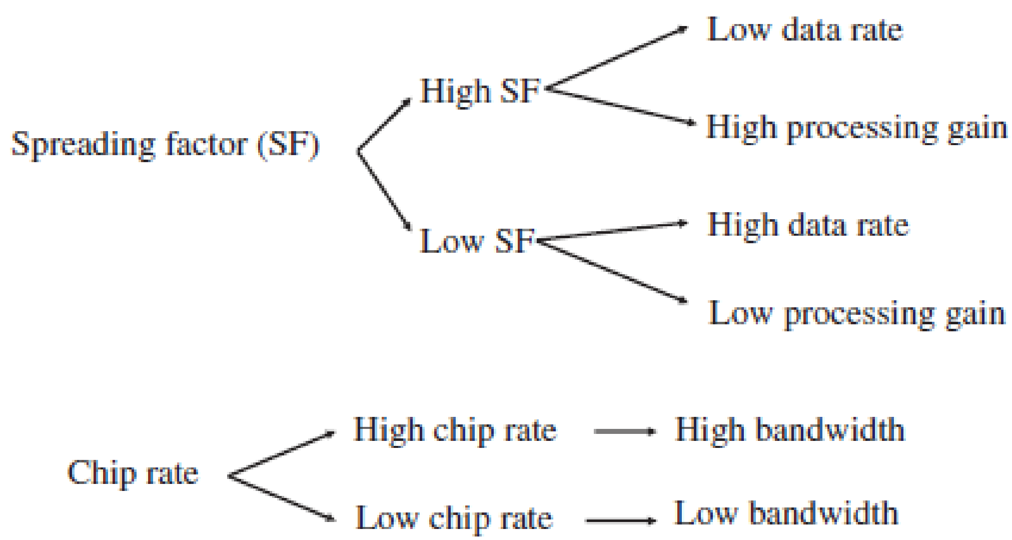
Spreading code = Scrambling code & Channelization code

- Scrambling codes
  - Separates different users (in uplink)
  - Separates different cells (in downlink)

- Channelization codes
  - Separate different users in the downlink.
  - Separate different channels of the same user in the uplink.

Spreading Factor

- Spreading factor (SF): the number of chips used to encode a single bit
- Chip rate: the speed the chips are transferred over air interface (3.84 Mchips/s for UMTS).
- Process gain: the ratio of the spread bandwidth to the original bandwidth.
- TX Power/SF trade-off (with higher SPs, one can lower the power and achieve the same error rate.)



Different Rates

Symbol_rate = Chip_rate/SF

Bit_rate = Symbol_rate*2

Dedicated Physical Data Channel overhead

User_bit_rate = Channel_bit_rate/2

Spreading Factor (SF)	Channel symbol rate	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Maximum user data rate with ½-rate coding (approx.)
512	7.5	15	3–6	1–3 kbps
256	15	30	12–24	6–12 kbps
128	30	60	42–51	20–24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4, with 3 parallel codes	2880	5760	5616	2.3 Mbps

Half rate speech

Full rate speech

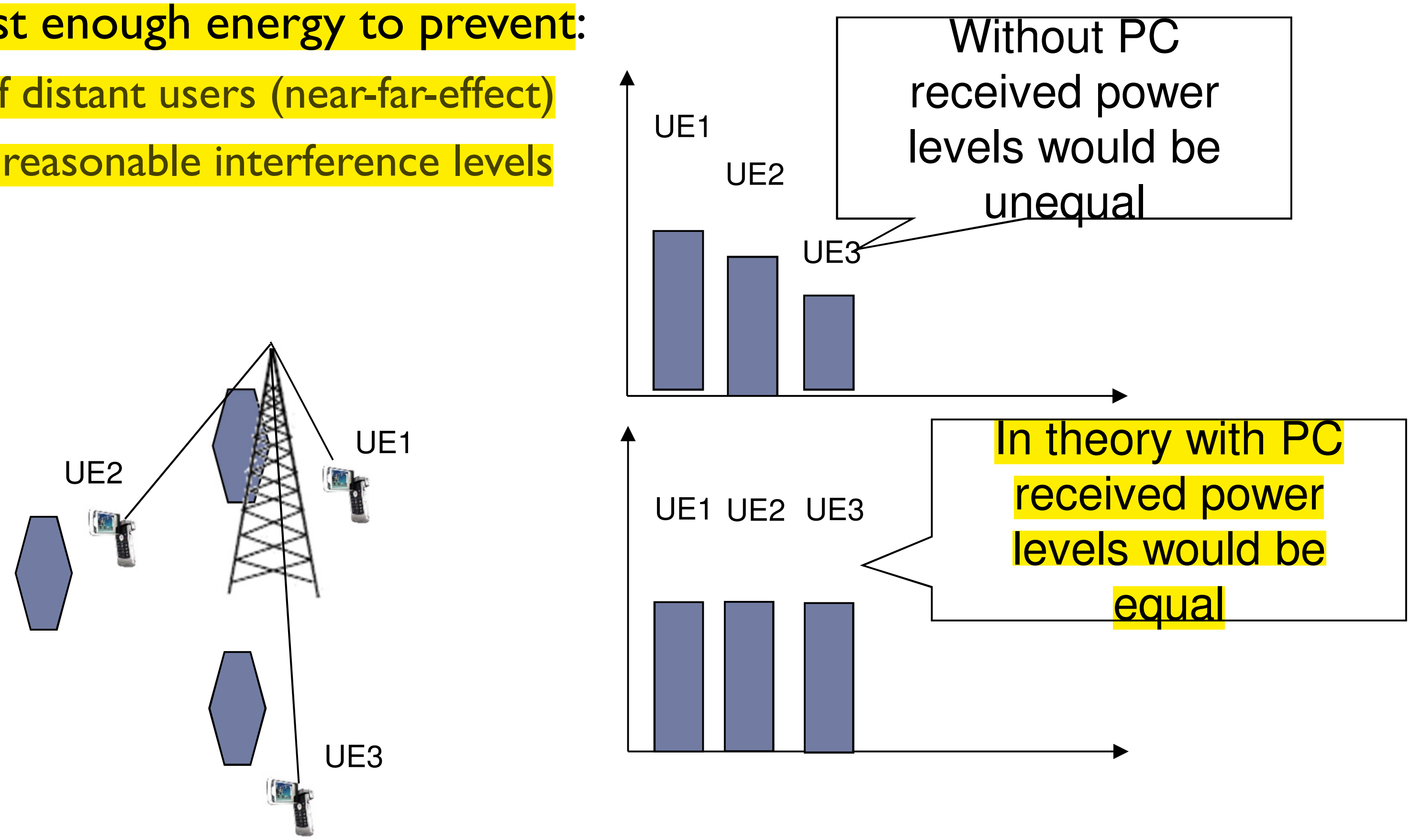
144 kbps

384 kbps

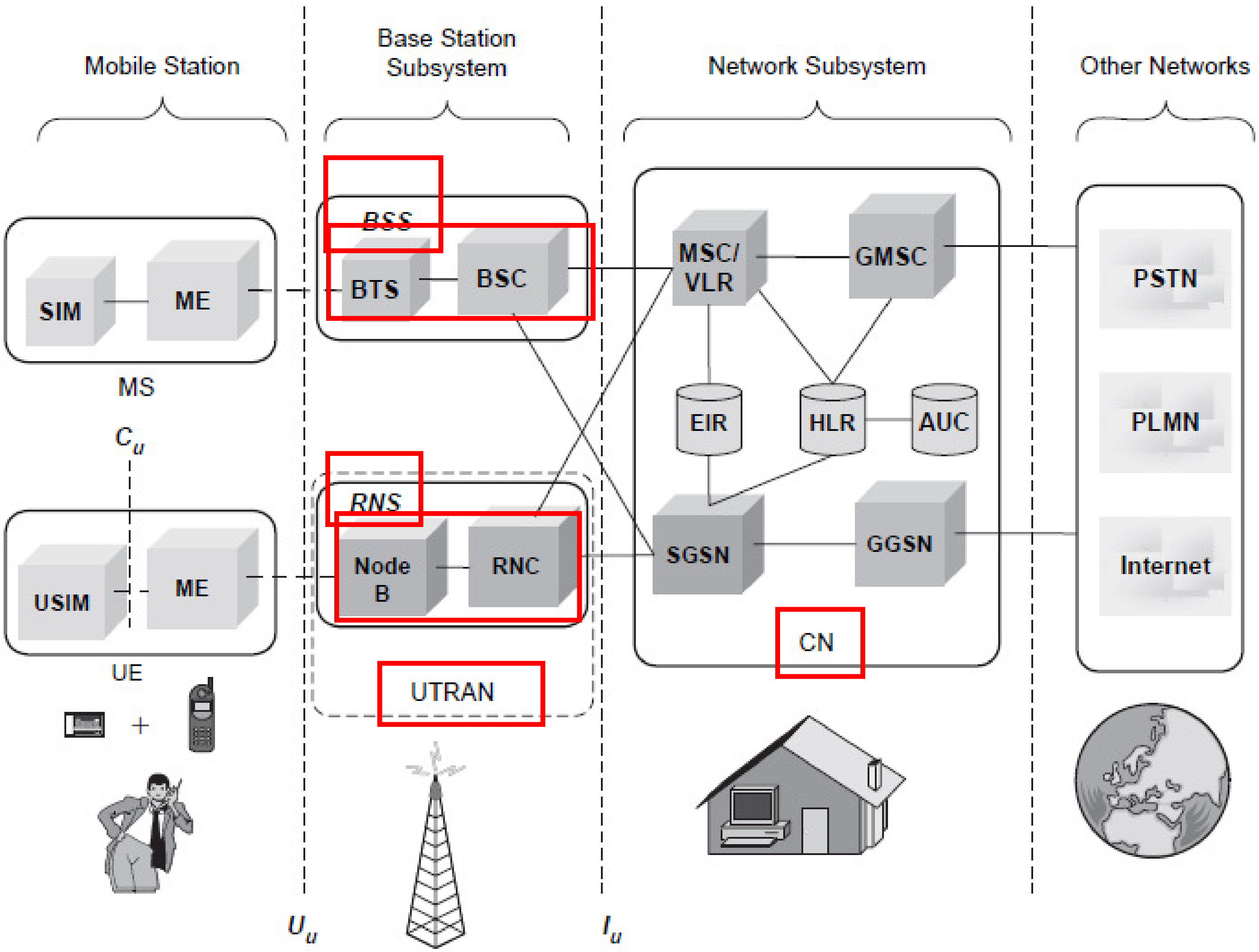
2 Mbps

Power Control in WCDMA

- The purpose of power control (PC) is to ensure that each user receives and transmits just enough energy to prevent:
  - Blocking of distant users (near-far-effect)
  - Exceeding reasonable interference levels

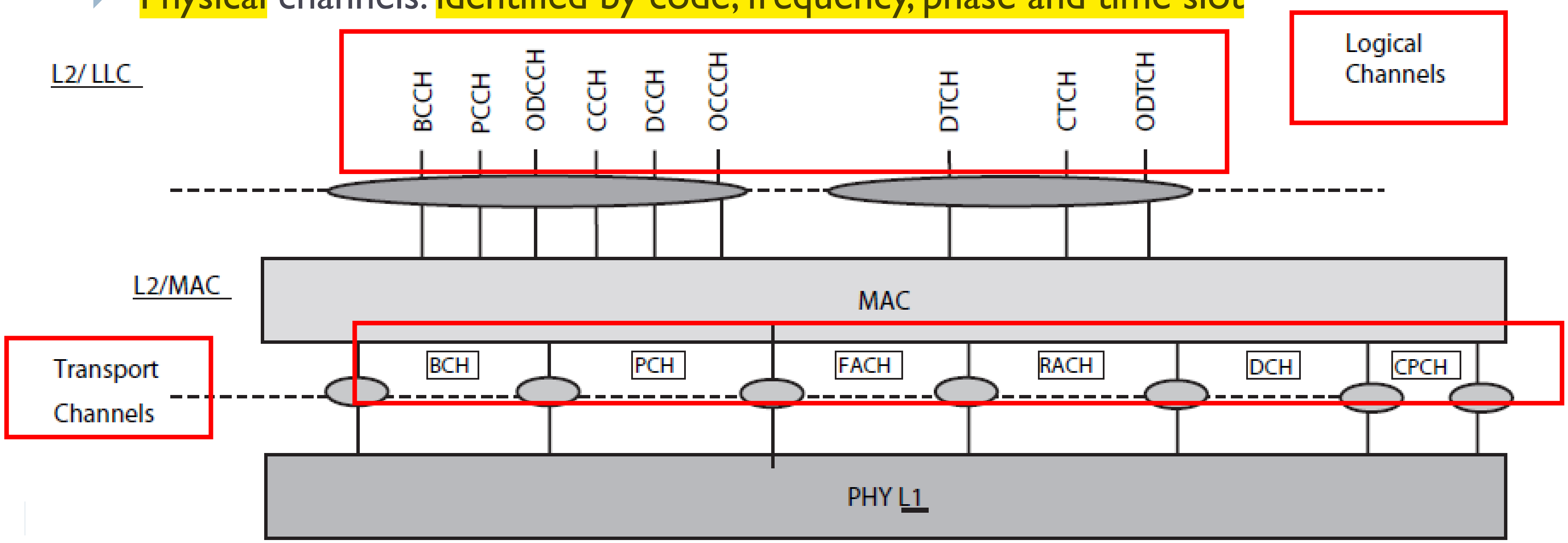


UMTS Network Architecture



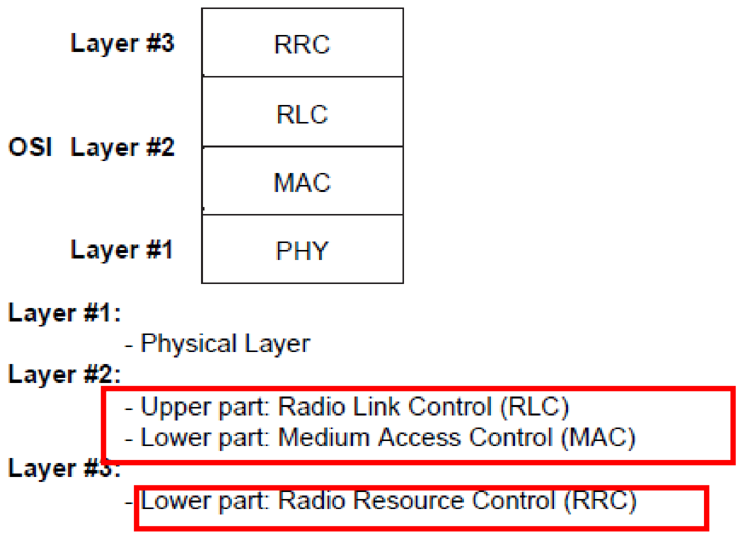
UTRAN Channels

- The channels in UTRAN are physical, transport, and logical.
  - Logical channels:
    - Used by MAC layer to provide data transport services to upper layers
    - Differentiate various application
  - Transport channels:
    - offer information transfer services between MAC and PHY
    - Differentiate various transmissions
  - Physical channels: identified by code, frequency, phase and time slot



Uu Interface

- The radio interface, *Uu*, is the interface between UE and UTRA.
- Its lower parts consists of three layers
  - Layer 1: physical layer,
  - Layer 2: data link layer (MAC and RLC),
  - Layer 3: network layer (RRC),



Uu MAC Layer

- The MAC layer provides data transfer services on logical channels.
- MAC is responsible for:
  - Selection of appropriate transport format (basically bit rate) within a predefined set, per information unit delivered to the physical layer
  - Service multiplexing on *random access channel* (*RACH*), *forward access channel* (*FACH*), and *dedicated channel* (*DCH*)
  - Priority handling between data flow of a user as well as between data flows from several users
  - Access control on RACH and FACH

Radio link control (RLC)

- Upper part of layer 2 is responsible for
  - Segmentation and assembly of the packet data unit
  - Transfer of user data
  - Error correction through retransmission
  - Sequence integrity
  - Duplication information detection
  - Flow control of data

RLC Layer Operation Modes

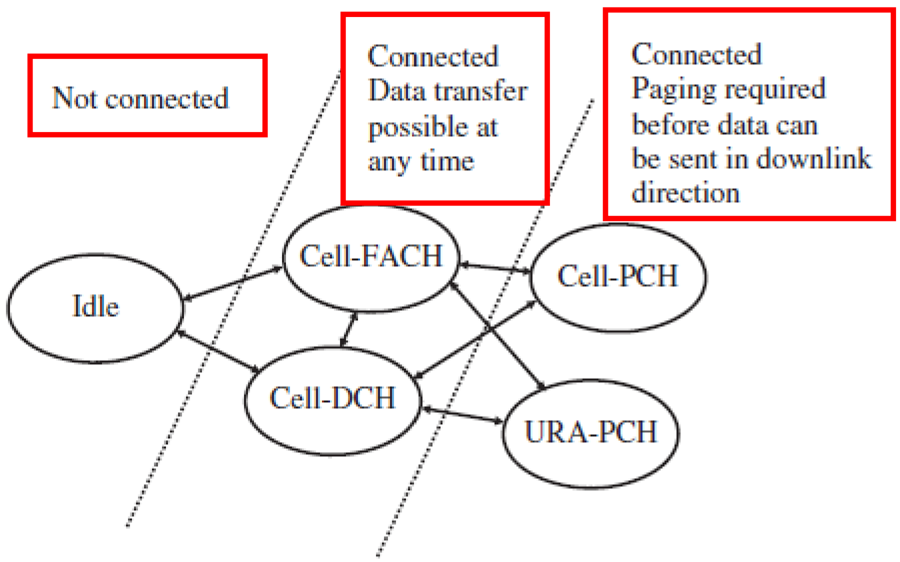
- Three different modes for RLC operation
  - RLC Transparent mode:
    - Used for voice traffic, broadcast, and paging
    - No acknowledgement, no change in the data
  - RLC unacknowledged mode:
    - Offers segmentations and concatenations
    - Data can be padded
  - Acknowledged mode:
    - Window size is fixed and negotiated between NodeB and UE.
    - Offers flow control, window based ARQ
    - Used for IP frames,

Radio Resource Control (RRC)

- Layer 3 is in charge of
  - Setting up, reconfigure and re-establish radio bearers.
  - Cell Broadcast Service (CBS) control.
  - Initial cell selection and cell re-selection.
  - Paging
  - Control of requested QoS,
  - UE measurement reporting and control of the reporting.

Radio Resource Control (RRC) States

- Idle
  - mobile device is attached to the network but does not have a physical or logical connection with the radio network.
  - May have an IP address
  - Entered this state due to long inactivity

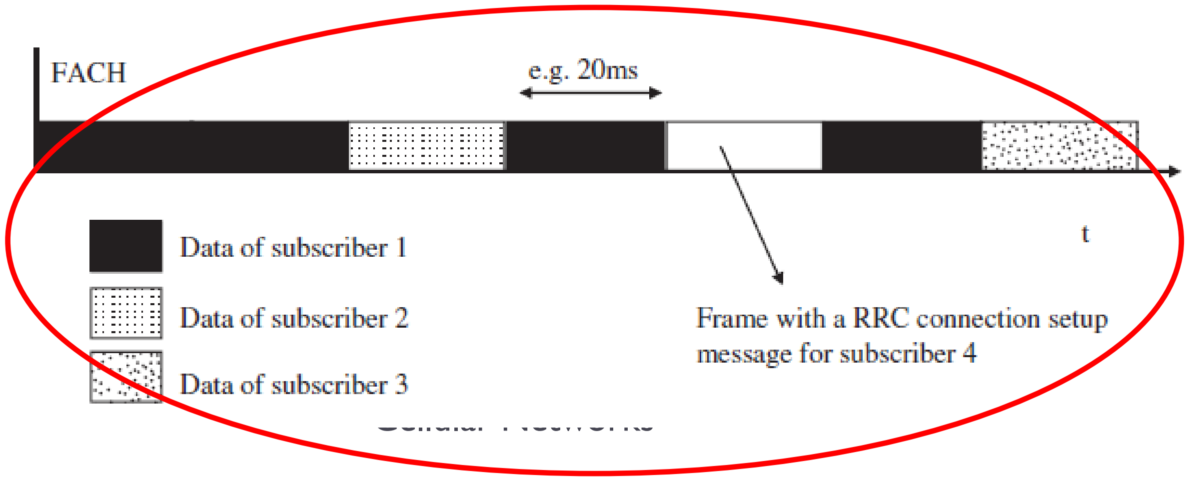


Radio Resource Control (RRC) States

- Cell_DCH
  - a physical connection is established between UE and NodeB.
  - In the UTRAN, this means UE has its own spreading code in the downlink direction and its own spreading and scrambling codes in the uplink direction.
  - The resources are not released if the connection is inactive.
  - This significantly decreases the delay
  - Other users benefit from lower interference.

Radio Resource Control (RRC) States

- Cell_FACH
  - Used when only a small amount of data needs to be transferred to or from a subscriber.
  - Neither an uplink nor a downlink dedicated physical channel is allocated to the UE.
  - The UE continuously monitors a FACH in the downlink
  - Uplink data frames are sent via the RACH.
  - The UE is known on cell level according to the cell where the UE last made a cell update.



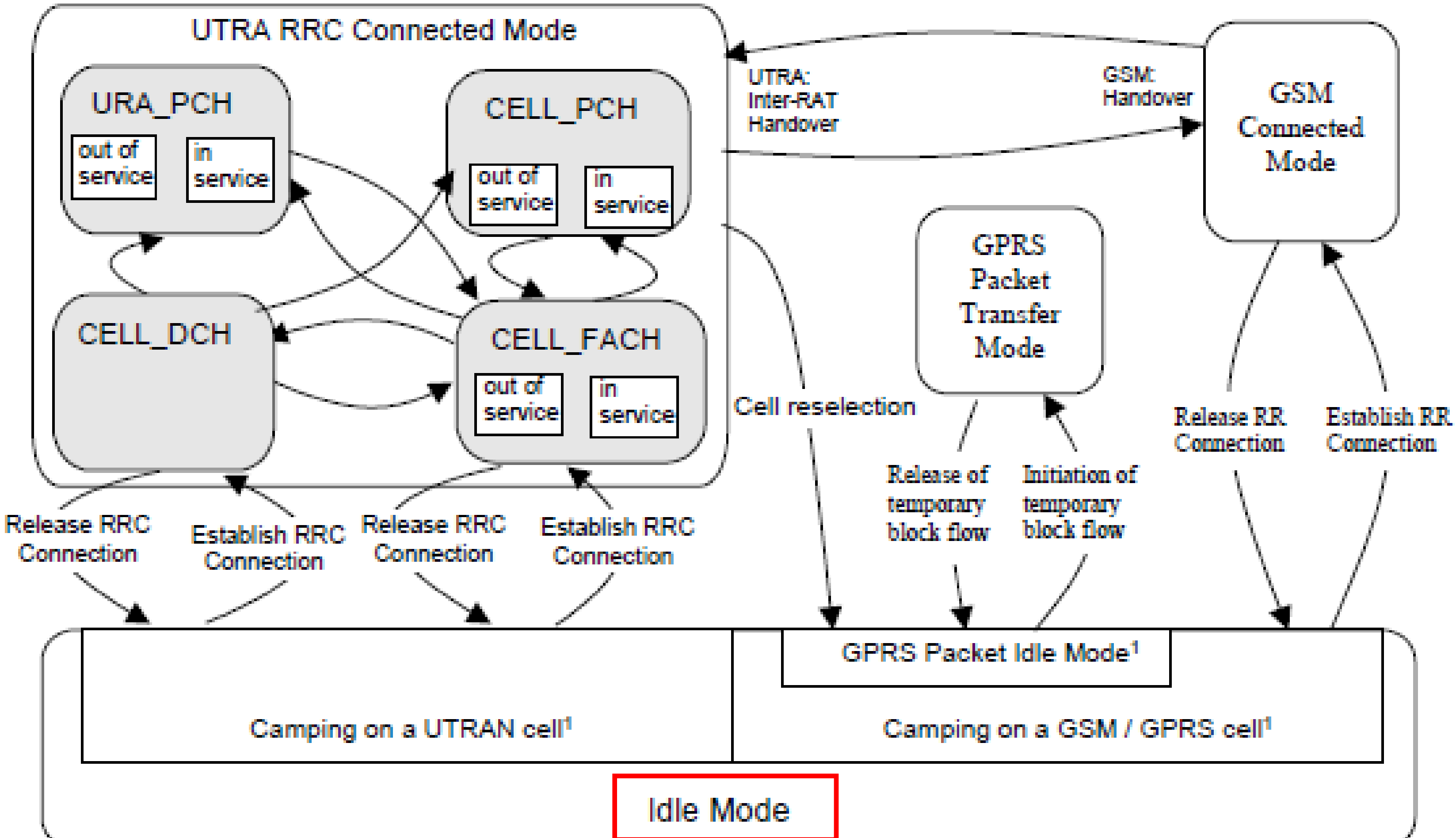
Radio Resource Control (RRC) States

- Cell_PCH
  - UE known at a cell level but can be reached via PCH.
  - Neither an uplink nor a downlink dedicated physical channel is allocated to the UE
  - The UE monitors PCH.
  - No uplink activity is possible.
  - If data arrives, the UE needs to be paged first.
  - The mobile device then responds and implicitly changes back to Cell-FACH state.

Radio Resource Control (RRC) States

- URA_PCH
  - When there are several cell changes.
  - RNC is not aware of the cell location.
  - The UE is known on URA level according to the URA assigned to the UE during the last URA update in CELL_FACH state.
    Neither an uplink nor a downlink dedicated physical channel is allocated to the UE
  - No uplink activity is possible
    - If the UE wants to make an uplink access it autonomously enters the CELL_FACH state.

RRC State Transition Including GSM



Radio Network Controller (RNC)

- The RNC is the heart of the new access network, replacing BSC and PCU.
- All decisions of the network operation are made at RNC.
- An RNC is responsible for control of all the BTSs that are connected to it, and maintains the link to the packet and circuit core network.
- It also needs to be capable of supporting interconnections to other RNCs, a new feature of UMTS.
- Most of the decision-making process is software based, so a high processing capacity is required.
- This chapter deals with much of the functionality of the RNC, such as radio resource management (RRM).

Radio Network Controller (RNC)

- RNC Tasks:
  - Radio resource management.
  - Link maintenance.
  - Hand-over control.
  - Mobility management,

RNC Interface Functions

- Node-B Application Part (NBAP):
  - Signalling protocol responsible for the control of the Node B.
  - NodeB Control Port (NCP) which handles common NBAP procedures and Communication Control Port (CCP) which handles dedicated NBAP procedures.
- Access Link Control Application Protocol (ALCAP)
  - Control plane protocol for the transport layer.
  - Basic functionality of ALCAP is multiplexing of different users onto one AAL2 transmission path.
- Radio Access Network Application Part (RANAP)
  - Signalling protocol responsible for communication between RNC and the core network.
- Radio Network Subsystem Application Part (RNSAP)
  - Signalling protocol responsible for communications between RNCs.

Radio Resource Management (RRM)

- RRM is part of RNC implemented as a software.
- Goal: TRAN resource managements.
- RRM functions:
  - Network based
    - Admission control
    - Packet scheduler
    - Load control
  - Connection based
    - Handover control
    - Power control

Radio Resource Management (RRM)

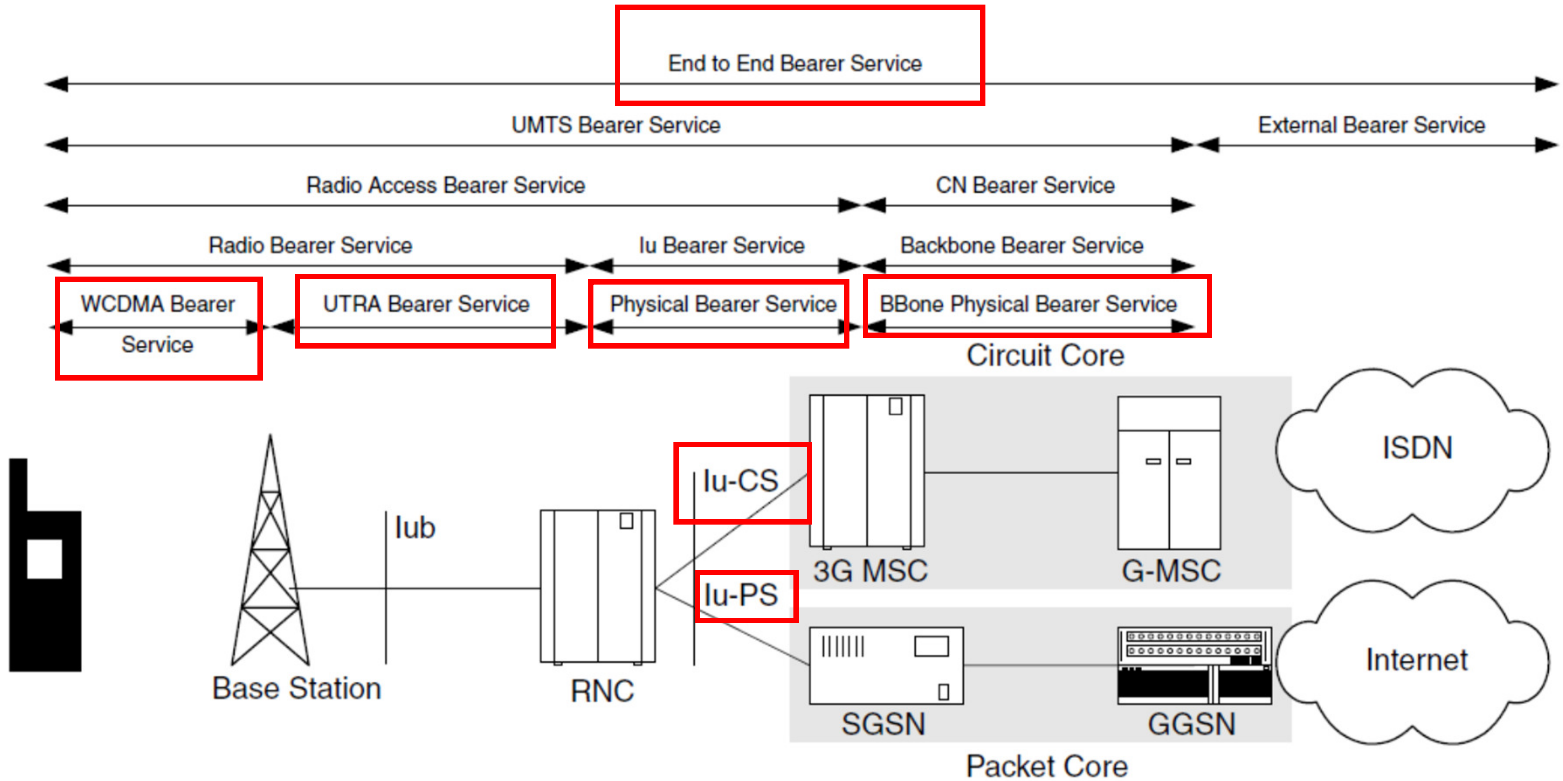
- Admission control: more than just available codes
  - Received signal strength of the current and surrounding cells;
  - Estimated bit error rate of the current and surrounding cells;
  - Received interference level;
  - Total downlink transmission power per cell.
- Scheduler:
  - The packet scheduler uses the resources not currently allocated to schedule non-real-time data.

Radio Resource Management (RRM)

- Load control:
  - The current mobile devices could increase their power
  - The new mobile device could be granted a lower data rate than requested.
  - Other voice call users could be shifted over to GSM if there is coverage.
  - Handover could be performed for high data rate users.
  - Users on the fringe of the cell could be asked to move to other cells.
  - Calls could be dropped in some controlled way.
  - Use outer loop power control to reduce uplink signal to interference ratio (SIR).
  - Users who have been allocated dedicated channels but who have a low utilization can be moved to the shared or common channels.

UMTS Bearer Service

- Network services are end-to-end which has a QoS required by the user.
- To realize a certain network QoS, a bearer service with well-defined characteristics must be set up.
- A bearer is a connection with specific QoS requirements.



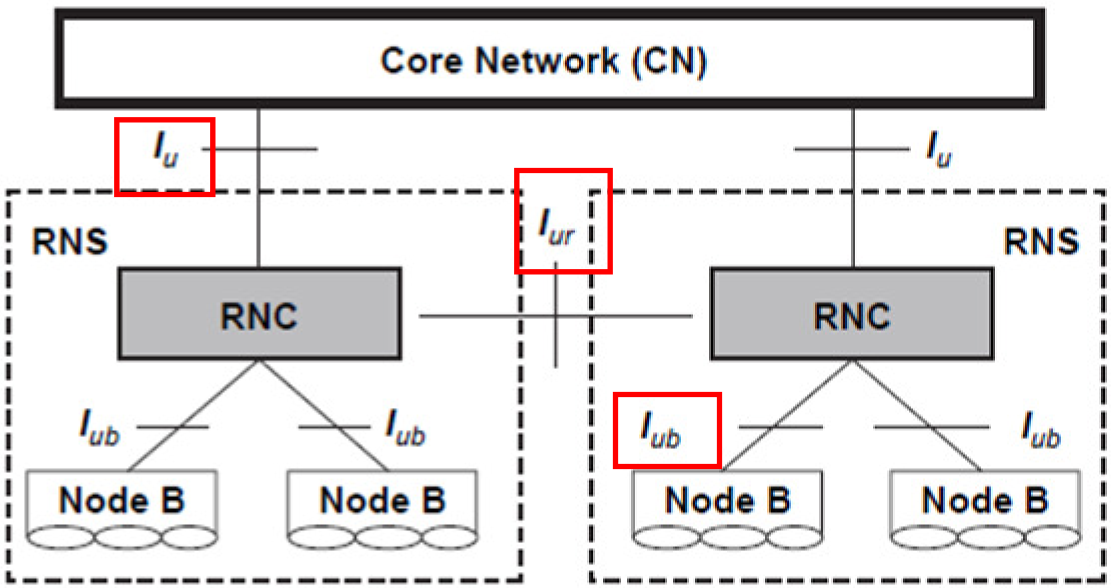
QoS Parameters of a RAB service

- Radio access bearer attributes for different classes.

Traffic class	Conversational class	Streaming class	Interactive class	Background class
Maximum bit rate (kbps)	<2000	<2000	<2000 overhead	<2000 overhead
Delivery order	Yes/No	Yes/No	Yes/No	Yes/No
Maximum SDU size (octets)	<1500	<1500	<1500	<1500
SDU format information	(1)	(1)	(1)	(1)
SDU error ratio	10^{-2}, 10^{-3}, 10^{-4} 10^{-5}	10^{-2}, 10^{-3}, 10^{-4} 10^{-5}	10^{-3}, 10^{-4} 10^{-5}	10^{-3}, 10^{-4} 10^{-5}
Residual bit error ratio	$5*10^{-2}$, 10^{-2}, 10^{-3}, 10^{-4}	$5*10^{-2}$, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$
Delivery of erroneous SDUs	Yes/No	Yes/No	Yes/No	Yes/No
Transfer delay (ms)	80, maximum	500, maximum		
Guaranteed bit rate (kbps)	<2000	<2000		
Traffic handling priority			TBD	

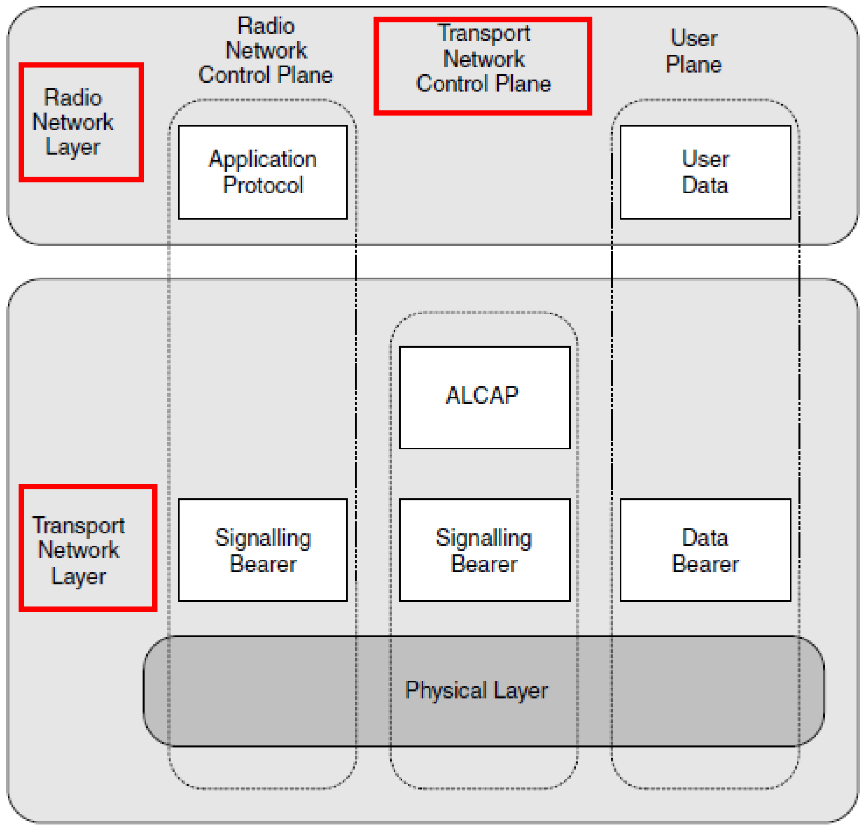
UTRAN Interfaces

- The open logical interface that interconnects
  - Iu: UTRAN to the UMTS core network
  - Iur: RNC to another RNC
  - Iub: RNC to NodeB



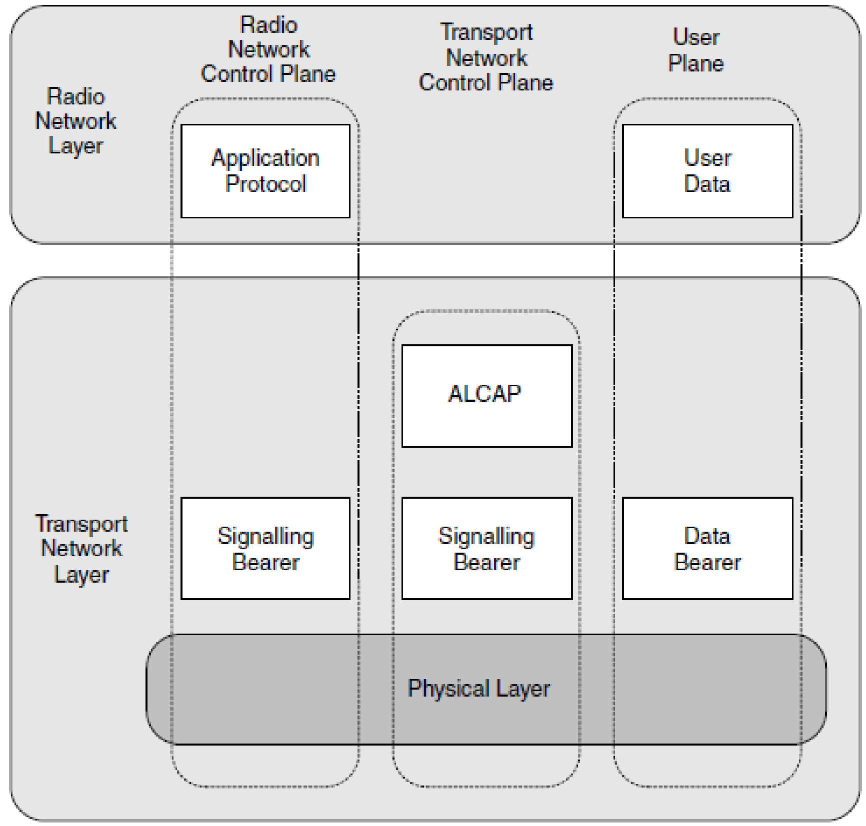
UTRAN Interfaces

- Each interface consists of
  - Two horizontal layers:
    - Radio network layer
    - Transport network layer
  - Three different planes (vertical):
    - Radio network control plane (RNCP),
    - Transport network control plane (TNCP),
    - User plane (UP).



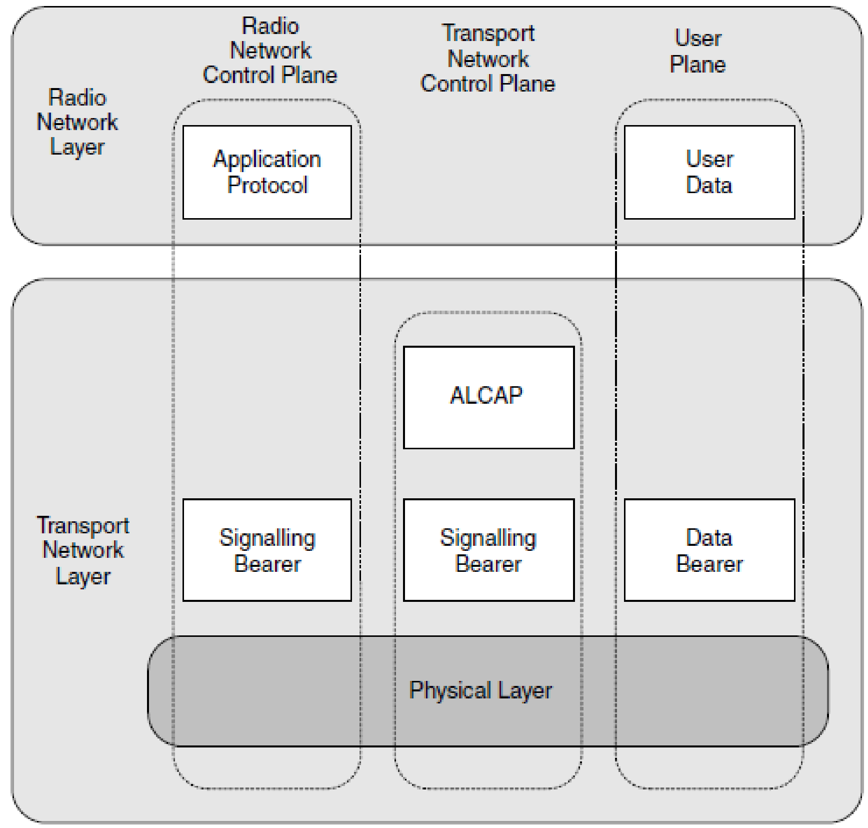
UTRAN Interfaces

- Radio Network Layer
  - All UTRAN related issues,
- Transport Network Layer
  - represents standard transport technology that is selected to be used for UTRAN
  - Without any UTRAN specific requirements.
  - offers the service of transport bearers for both signalling and data streams, where the signalling is the application protocol of the upper layer.
  - Currently using ATM in 3G, IP in 4G



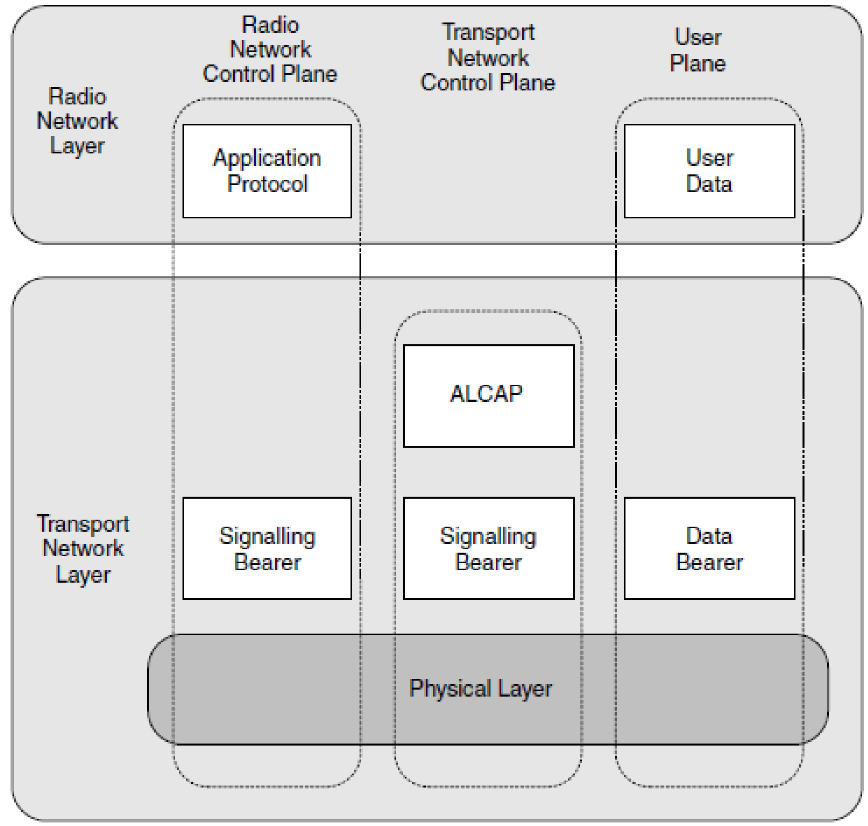
UTRAN Interfaces

- User Plane:
  - Used for exchange of user data
  - serves two service domains:
    - packet-switched (PS) domain
    - circuit-switched (CS) domain.
- Radio Network Control Plane
  - Used for exchange of all UMTS-specific control signaling.
  - Carries information for
    - general control of UTRAN operations.
    - control of UTRAN in the context of each specific call.
  - Application protocol is used for setting up bearers between network components.



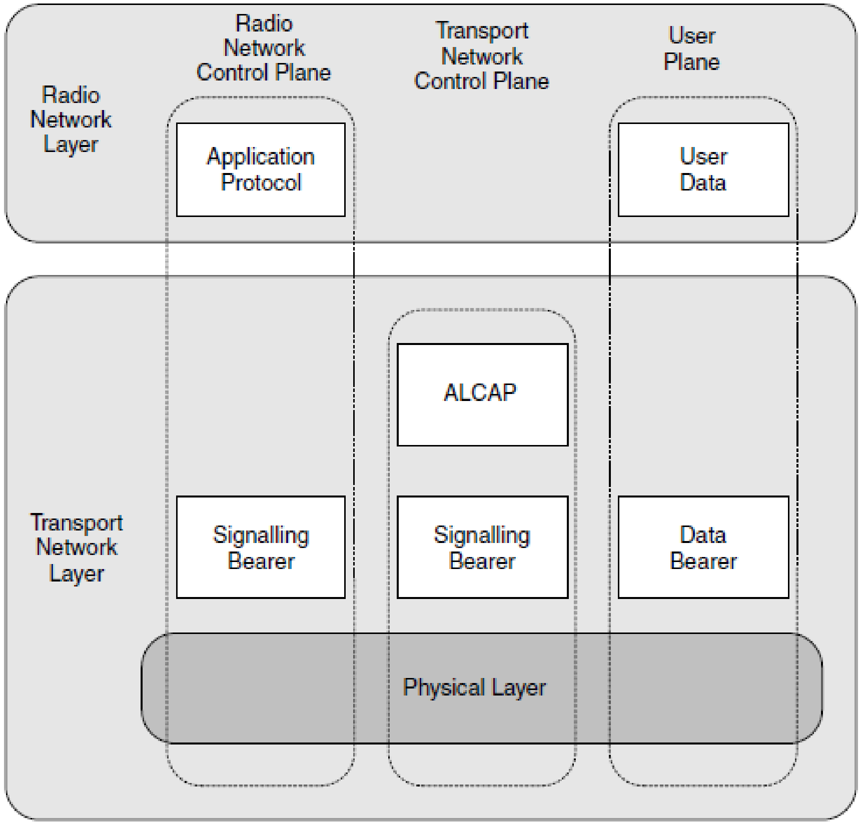
UTRAN Interfaces

- Transport Network Control Plane:
  - It sets up the transport bearers (data bearers) for the user plane.
  - The transport network layer needs its own control plane to establish, manage and release its own bearers.
  - The generic name for this control plane component is the *access link control application protocol (ALCAP)*.
  - ALCAP receives commands from application protocol.
  - It is designed to make the interfaces independent of transport technology.
  - In the context of UMTS, the transport network is ATM.



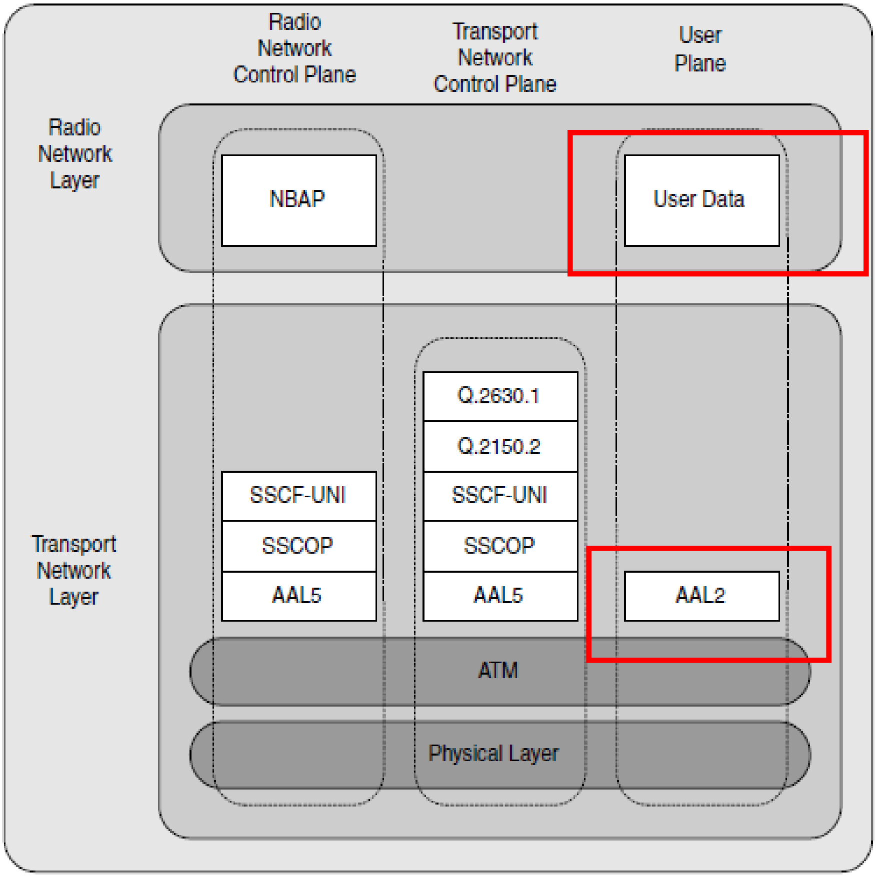
UTRAN Interfaces

- A simple example of how these different protocol stacks may interact with each other is:
  - A NAS message such as a CM service request would be sent from the higher layers of the user plane of the UE.
  - This would request that the network instruct the radio network control plane to set up a radio bearer.
  - The radio network control plane would then ask the transport network control plane to actually do this.



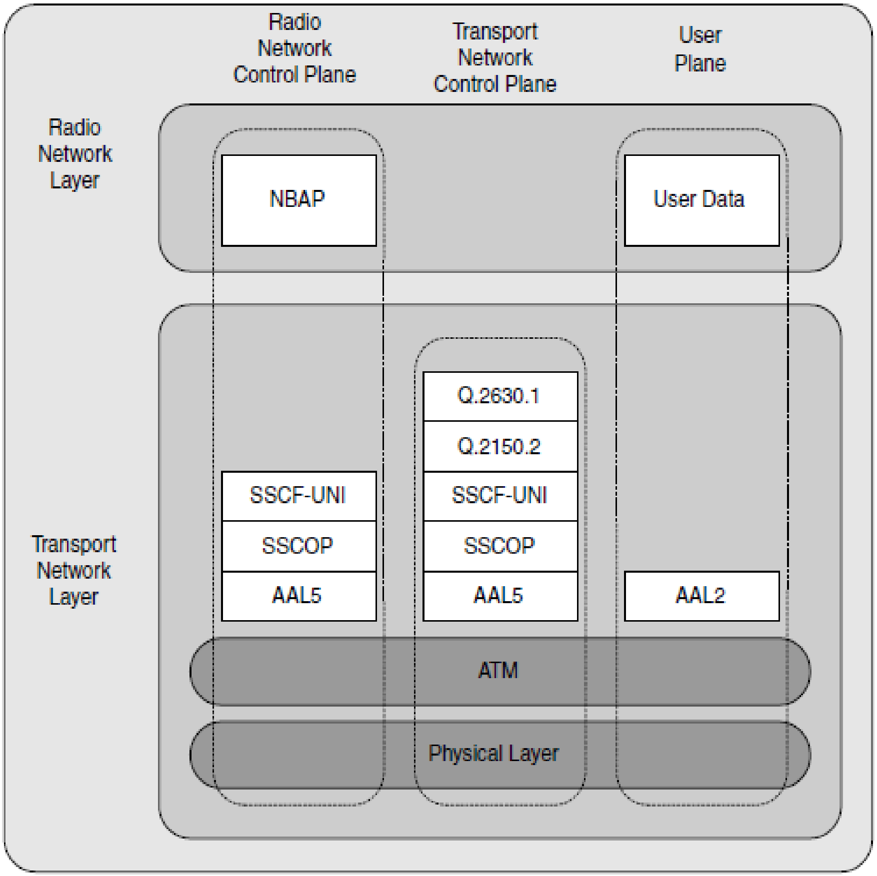
Iub Interface

- The logical interface that interconnects RNC and NodeB.
- User plane part of the radio network layer consists of the transport channels, for example, the FACH and RACH, DCH etc.
- In the transport network layer, the radio network user plane is offered the AAL2 adaptation layer for transport of user data.



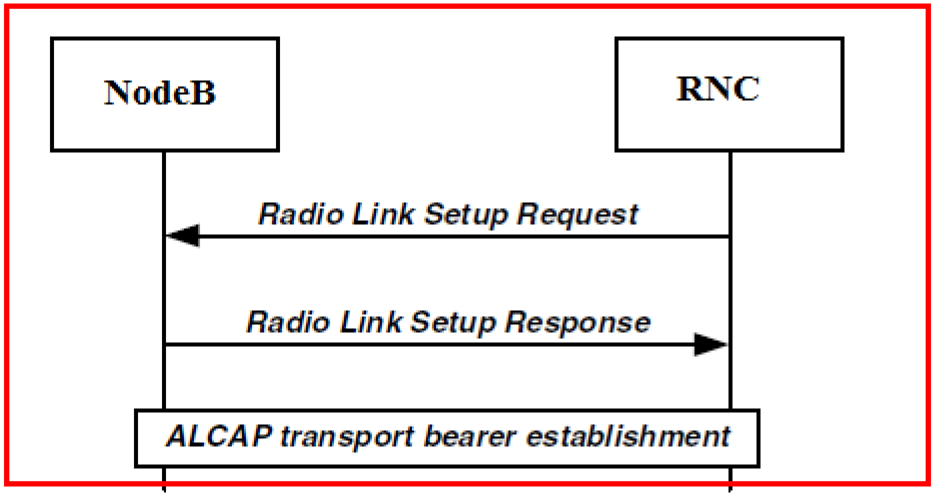
Iub Interface

- NodeB application part (NBAP):
  - Management of radio links: establishment, addition, and release of a radio link.
  - NodeB management: management of cell configuration and scheduling of broadcast information.
  - Common channel management: control of the common transport channels such as the RACH and FACH.
  - Fault management: reporting of general error situations.
  - Measurement and supervision – reporting and control of measurement information to the RNC, such as power measurements.



Iub Interface: Signaling Example

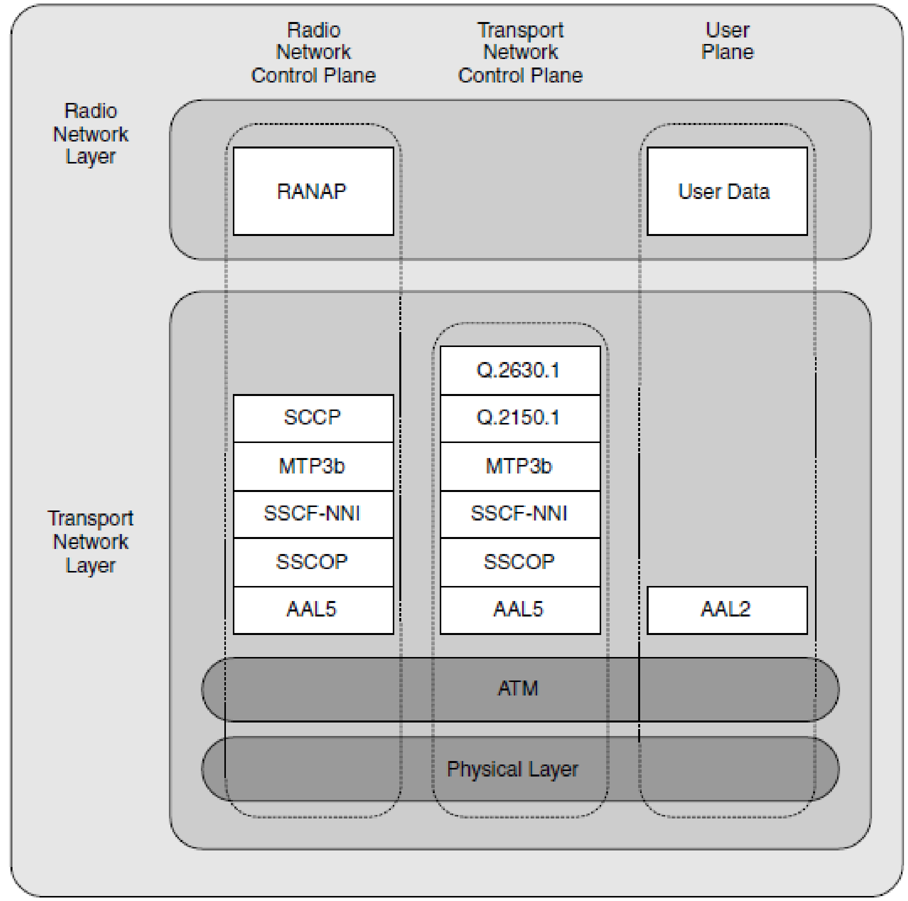
- NBAP signaling exchange exemple:
  - NBAP requets connection between nodeB and RNC.
  - NBAP sends radio link setup request ovear existing connections.
  - ALCAP creates beares for user plane.



Radio Link Setup Request
Uplink scrambling code
Transport format combination set (UL/DL)
Minimum UL spreading factor
Uplink SIR target
DL channelisation code
Power control information

Iu Interface

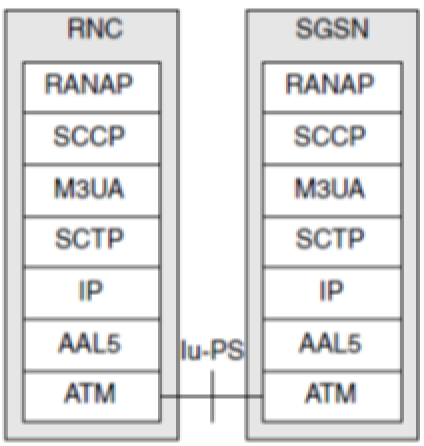
- The logical interface that interconnects one UTRAN to the UMTS MSC/SGSN.
- It has two user planes:
  - Circuit switch
  - Packet switch
- The Iu-CS connects to the 3G MSC and is much the same as the Iur interface.
- The control plane protocol stack consists of Radio access network application part (RANAP) on top of signaling system 7 (SS7) protocol stack.

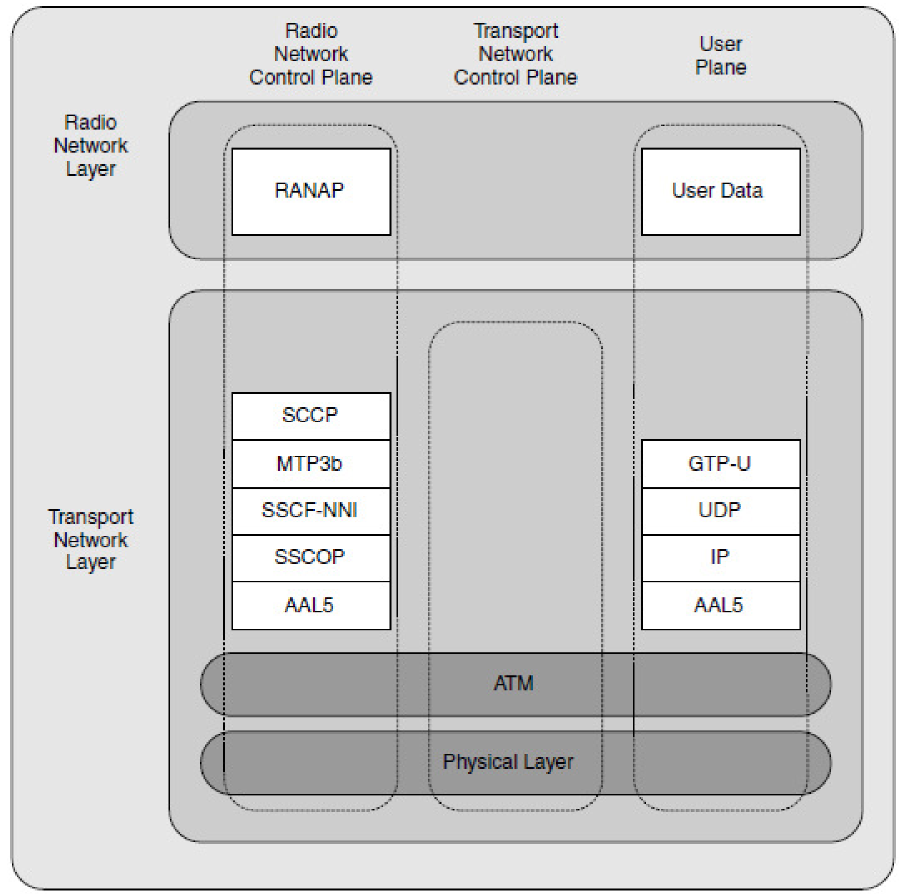


Iu-Circuit Switch (CS)

Iu Interface

- The logical interface that interconnects one UTRAN to the UMTS MSC/SGSN.
- Due to transportation of user data over a GPRS tunnel protocol (GTP) (IP over ATM connection), there is no need for any transport network signalling.

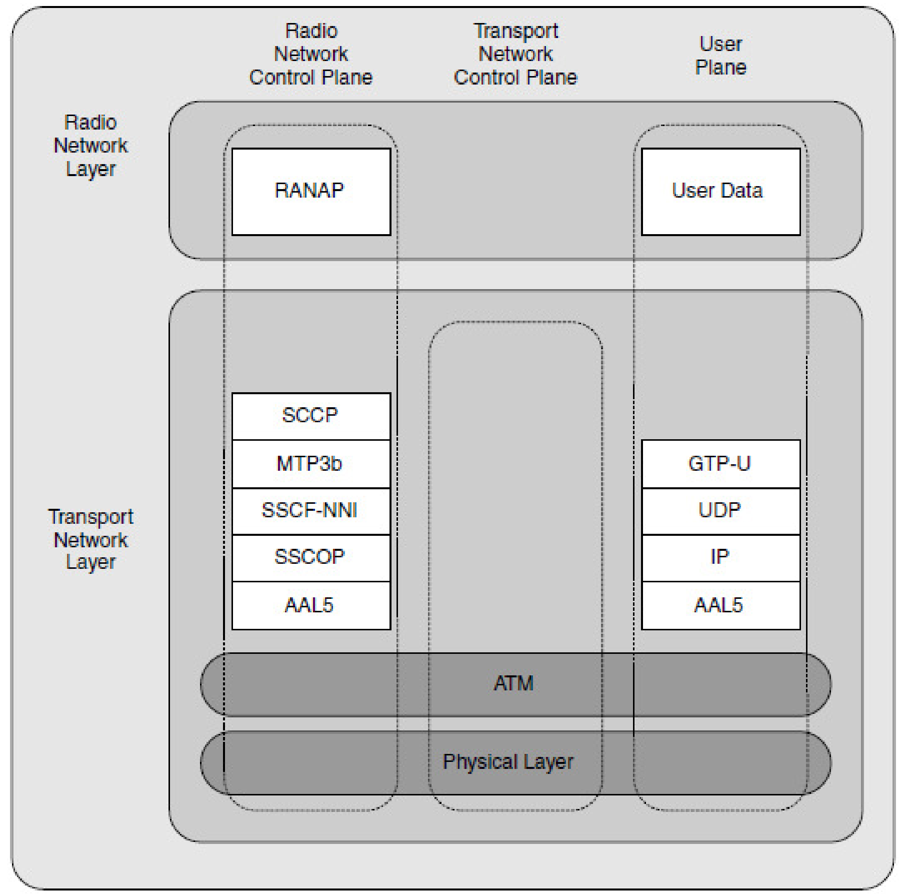




Iu-Packet Switch

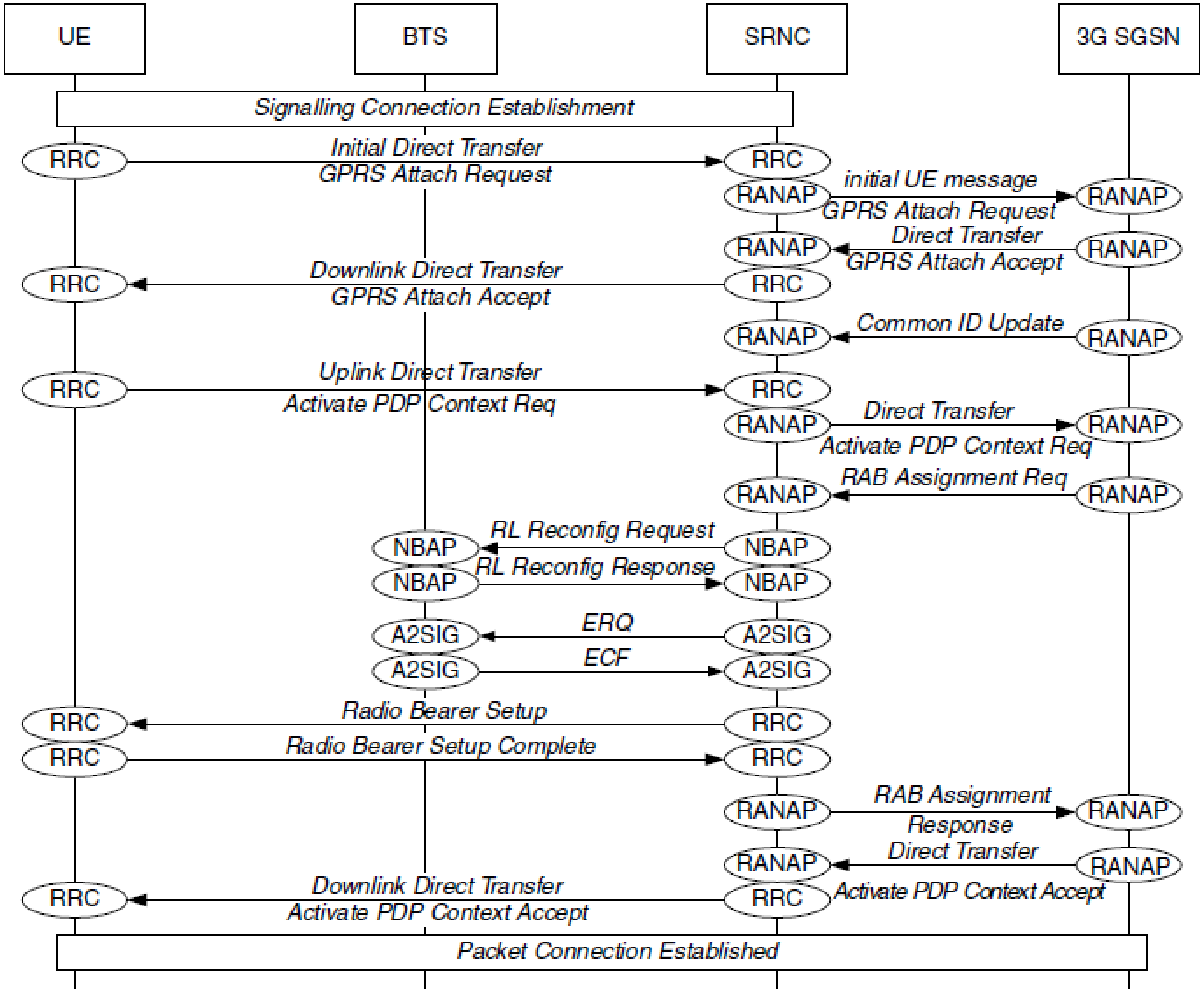
Iu Interface

- The logical interface that interconnects one UTRAN to the UMTS MSC/SGSN.
- The key RANAP functions are as follows:
  - Radio bearer management: establishment, modification and release of radio access bearers.
  - Serving RNC relocation: shifting of resources and functionality between RNCs.
  - Iu connection release
  - Iu load control
  - User paging
  - Transport of non-access stratum information



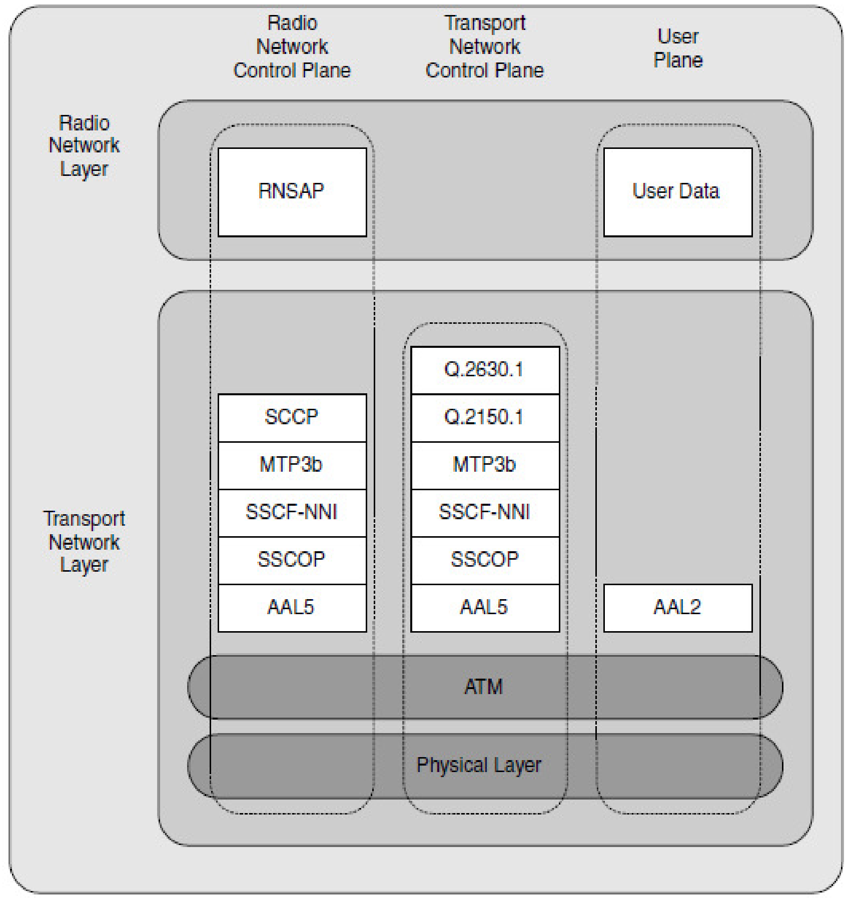
Iu-Packet Switch

Packet Connection Establishment Example



Iur Interface

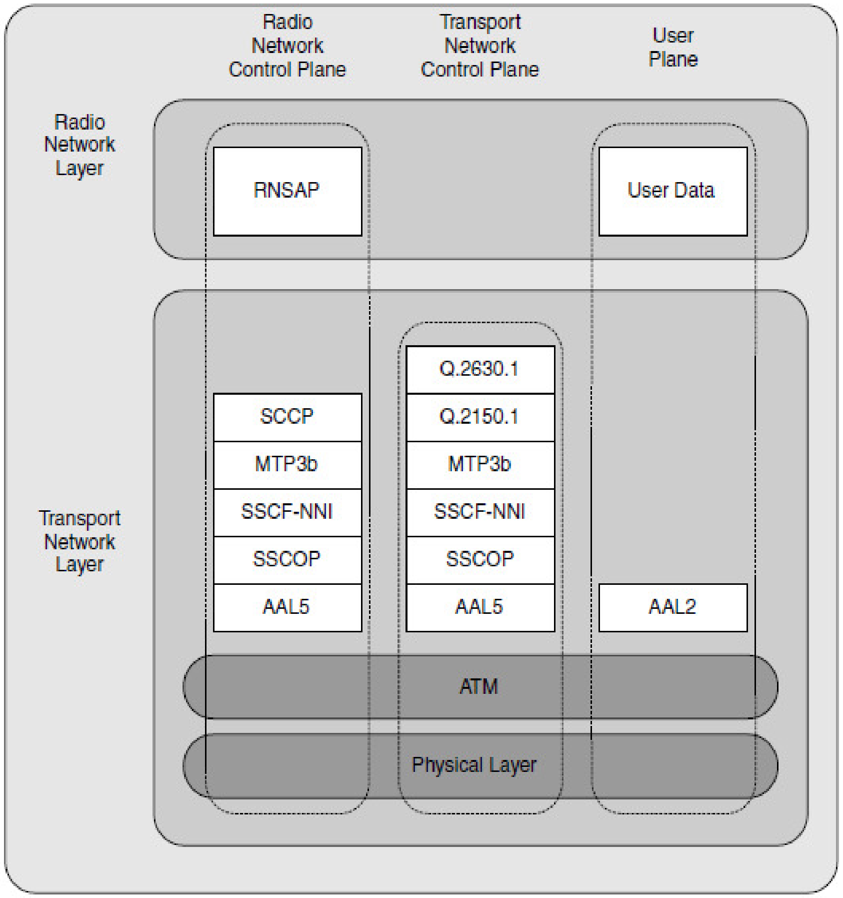
- The logical interface that interconnects RNCs.
- It is different from Iu and Iub interfaces in that only network level requests pass this interface.
- It is called network to network interface (NNI) interface.



Iur Interface

- The logical interface that interconnects RNCs.

- The functions of RNSAP may be broken into four key areas:
  - Basic mobility
  - Dedicated channels: procedures to handle dedicated channels on the Iur interface, such as management of radio links
  - Common channel: procedures related to common transport channels, e.g. RACH and FACH
  - Global: procedures that do not relate to a particular user context.

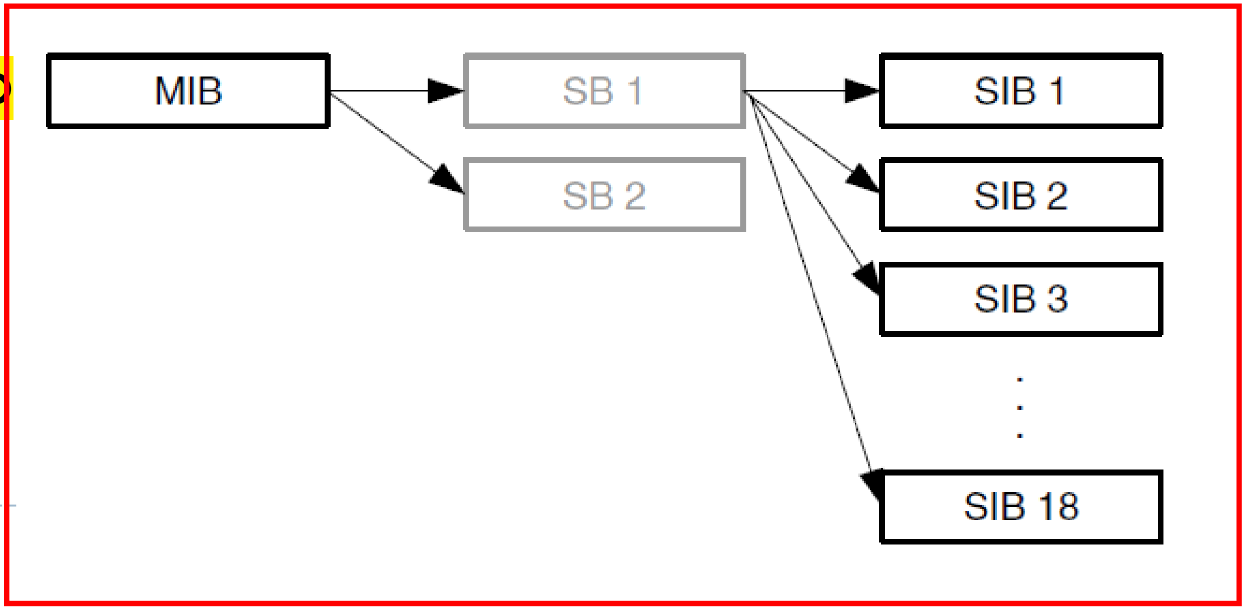


Broadcast System Information

- System information is carried in the downlink BCCH logical channel.
- It is mapped to the BCH and optionally the FACH transports.
- The BCH is carried at the physical channel PCCPCH.
- System information provides the UE with the necessary general parameters for both system and cell level to enable it to communicate with the network, such as details of the structure of the RACH and PRACH.

Broadcast System Information

- The system information is split into a number of system information blocks (SIB), where similar information is contained in one SIB.
- The scheduling and frequency of occurrence of these SIBs is referenced in a master information block (MIB).
- Optionally, up to two scheduling blocks (SB) may also be present containing SIB scheduling information.



Master information block (MIB)

- The specifications define 18 different SIBs.
- Typical usages are:

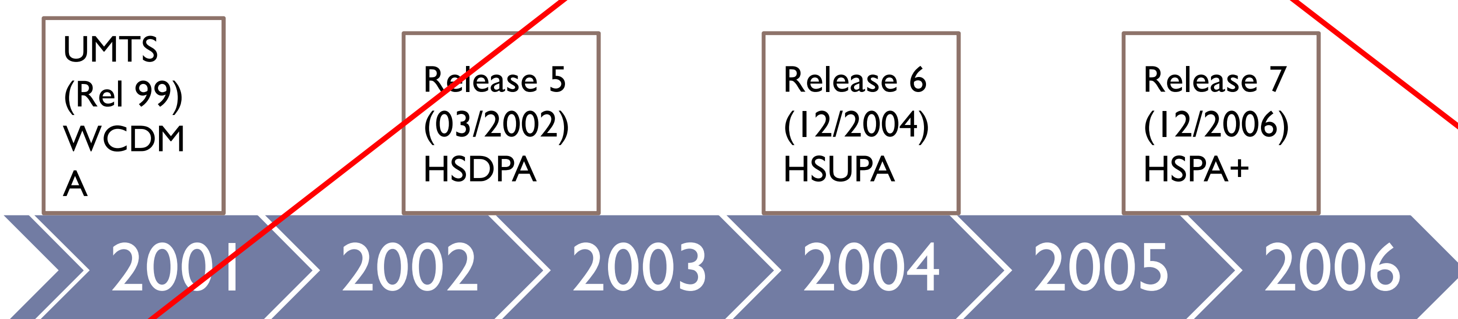
Information block	Description
MIB	SIB scheduling information
SB1	Optional SIB scheduling information
SB2	
SIB1	NAS system information as well as UE timers and counters to be used in idle mode and in connected mode
SIB2	URA identity
SIB3	Parameters for cell selection and reselection
SIB5	Parameters for the configuration of the common physical channels in the cell
SIB7	Fast-changing parameters uplink interference and dynamic persistence level
SIB11	Measurement control information to be used in the cell

Master information block (MIB)

- The MIB contains some basic information about the network, and scheduling information for the
  - The network information includes the supported PLMN types: GSM-MAP, ANSI-41 or both,
  - For GSM, the PLMN ID, which is the mobile country code (MCC) + mobile network code (MNC).
  - The scheduling information provides for each SIB present, the SIB type (SIB1, SIB2, etc.), the number of segments present in the SIB (SEG COUNT, 1–16), where the first segment is located (SIB POS), and how often it repeats on the channel, referenced to the system frame number (SFN).

High Speed Packet Access (HSPA)

- HSPA is the combination of two mobile telephony protocols,
  - High Speed Downlink Packet Access (HSDPA) and
  - High Speed Uplink Packet Access (HSUPA)
- Both extend and improve the performance of existing 3G mobile telecommunication networks utilizing the WCDMA protocols.



Technologies Adopted

- Shared downlink channels:
  - High-speed downlink shared channel (HS-DSCH).
  - High-speed shared control channel (HS-SCCH),
  - High speed dedicated physical control channel (HS-DPCCH).
- Shorter frame sizes
  - reduce trip time, to increase the granularity in the scheduling process, and to track the time varying radio channel better.
- Using high-order modulation, adaptive modulation, and coding MIMO.
- Hybrid ARQ (HARQ) retransmission schemes,