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UNIVERSITÄT FREIBURG

Communication Systems

UMTS

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Organization

- I. Data and voice communication in IP networks
- II. Security issues in networking
- **III. Digital telephony networks and voice over IP**

Final Lecture

- UMTS as the world wide 3G mobile standard
  - Network architecture and interfaces
  - User equipment and USIM
  - Core network functionality and protocols (packet switched and circuit switched domain)
  - UTRAN – UTMS radio network subsystem
    - RNS, RNC, Node B
  - Network based and connection based functions, power control and hand-over
  - Authentication and security

From GSM to 3rd generation mobile networks

- The short comings of GSM led to the development of a next generation mobile network
  - The new network
    - Should use the scarce resources of the shared medium “air” more efficiently
    - Should be really international (GSM had a primarily scope on Europe first)
  - Much higher data rates should be offered with reduced delays
  - Preferring the packet orientated approach over the circuit switched one – data services play an increasing role in mobility and voice could be just seen as data too (in reality is – voice is digitized and sent in packets in GSM already)

IMT2000 and UMTS

- International Telecommunication Union (ITU) defined demands for third generation mobile networks with the IMT-2000 standard
  - 3GPP (3G Partnership Project) continued that work by defining a mobile system that fulfills the IMT-2000 standard
  - Resulting system is called Universal Mobile Telecommunications System (UMTS)
  - Release '99 defined the bearer services with 64 kbit/s circuit switched and up to 384 kbit/s packet switched data rates
  - Location services and call services were defined: GSM-compatibility should be offered, the authentication and security will be upgraded to USIM

UMTS

- Several different paths from 2G to 3G defined
  - In Europe the main path starts from GSM when GPRS was added to the system
  - From this point it is possible to go to the UMTS system as we will see in core network structure of UMTS next lecture
  - In North America the system evolution will start from TDMA going to EDGE (last lecture) and from there to UMTS
- In Japan (the blind spot of GSM) two different 3G standards used
  - W-CDMA (which is compatible with UMTS) by NTT DoCoMo, Vodafone KK, and by new entrants

UMTS

  - cdma2000 (not compatible to European standards) which is very successfully used by KDDI
  - Transition to 3G was largely completed in Japan during 2005/2006
- UMTS system bases on layered services, like IP but unlike GSM
  - Top is the services layer, which will give advantages like fast deployment of services and centralized location
  - In the middle layer is control layer, which will help upgrading procedures and allow the capacity of the network to be dynamically allocated

UMTS

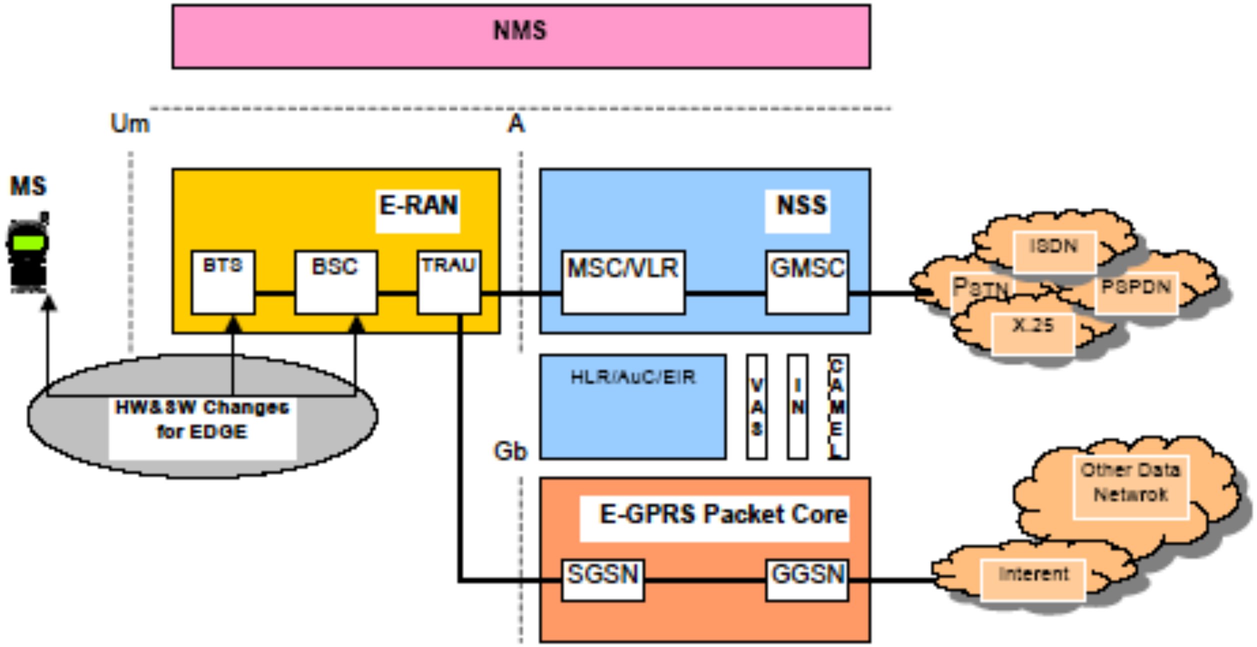
  - Bottom layer is handled by the connectivity layer where any transmission technology can be used and the voice traffic will transfer over ATM/AAL2 or IP/RTP
- UTMS will converge the mobile phone networks towards the IP world
  - Thus ATM is just the old existing traditional infrastructure used
  - Using IP in UMTS might push the IP world toward IPv6, because there will be a huge number of mobile phone subscribers (which might even exceed the number of IP dial-in Internet users)
- A lot of GSM infrastructure will be reused in UMTS networks

UMTS – history and planned standards

- Requirements toward a 3G standard
  - Fully specified and world-widely valid
  - Major interfaces should be standardized and open
- Services must be independent from radio access technology and is not limited by the network infrastructure
- Support of multimedia content and all of its components
- Convergence of existing networks

UMTS – history and planned standards

- Definition of GPRS (specific GPRS network elements are reused in 3G specification)
  - Reuse of operation and management components of GSM
  - Reuse of packetized data services infrastructure of GPRS

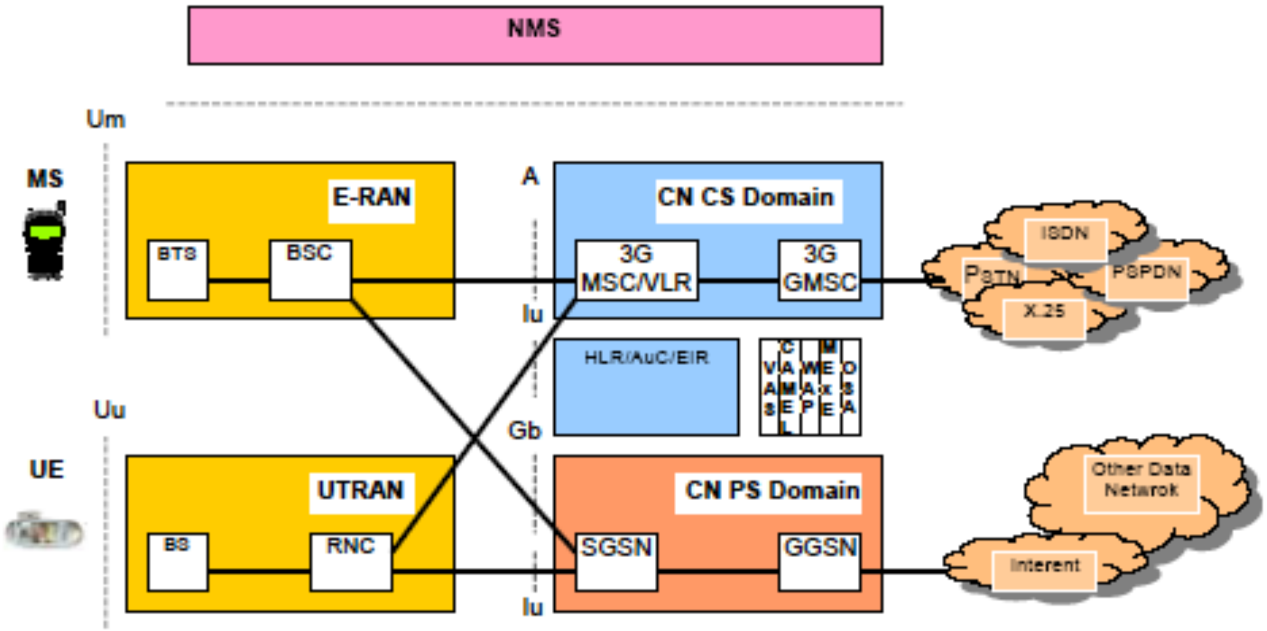


UMTS – history and planned standards

- February 1995 UMTS Task Force established; "The Road to UMTS" report
- December 1996 The UMTS Forum established. "European" WCDMA standard known as Universal Mobile Telecommunications System (UMTS)
- June 1997 UMTS Forum produces first report: "A regulatory Framework for UMTS"
- October 1997 ERC decided on UMTS core band.
- January 1998 ETSI meeting: W-CDMA and TD-CDMA proposals combined to UMTS air interface specification

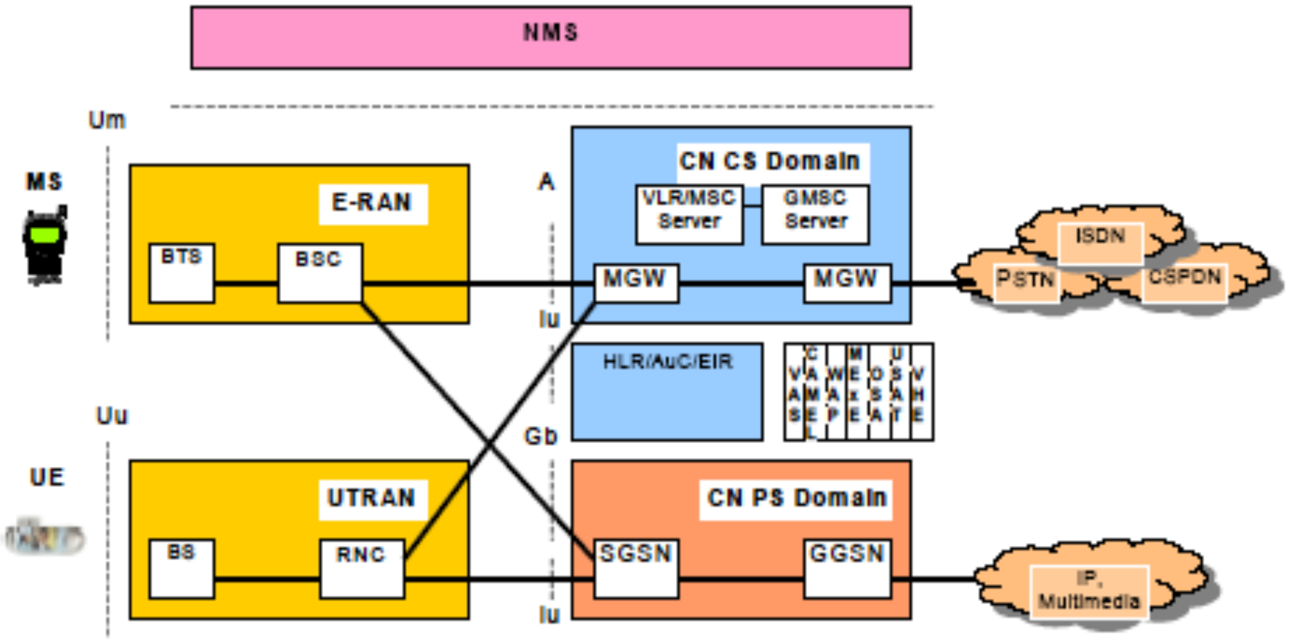
UMTS – history and planned standards

- June 1998 Terrestrial air interface proposals (UTRAN, WCDMA(s), CDMA2000(s), EDGE, EP-DECT, TD-SCDMA) were handed into ITU-R
- 3GPP Release ‘99



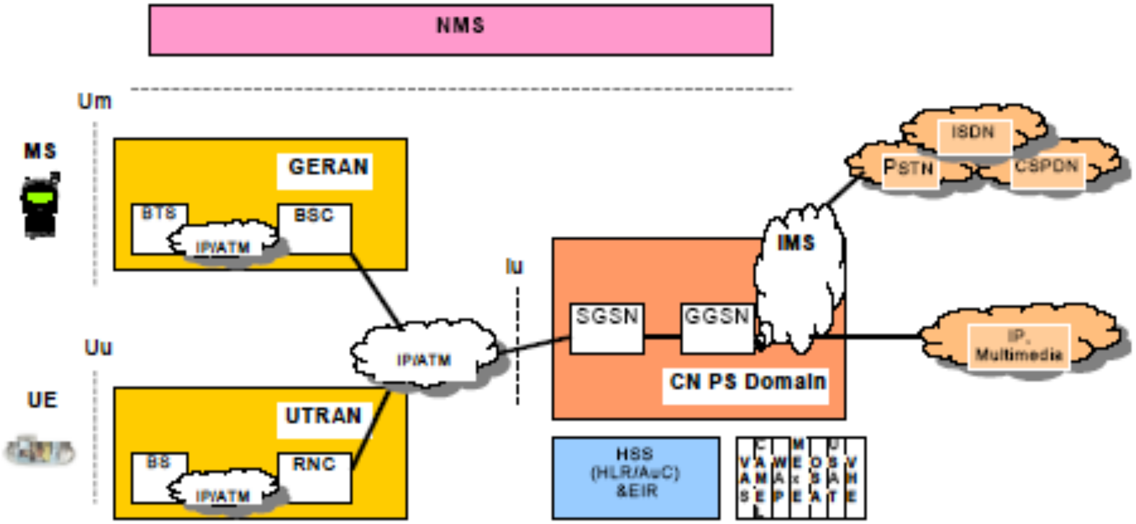
UMTS – history and planned standards

- December 1999 in Nice ETSI Standardization finished for UMTS Release 1999 specifications both for FDD and TDD
- March 2001 in Palm Springs 3GPP approves UMTS Release 4 specification



UMTS – history and planned standards

- Release 4 and 5 specifies an “All IP standard”
  - Streaming services (fast handover)
  - Seamless UMTS/WLAN integration, inter-working
  - Push-to-Talk over cellular
  - Presence for chat, instant messaging, ...

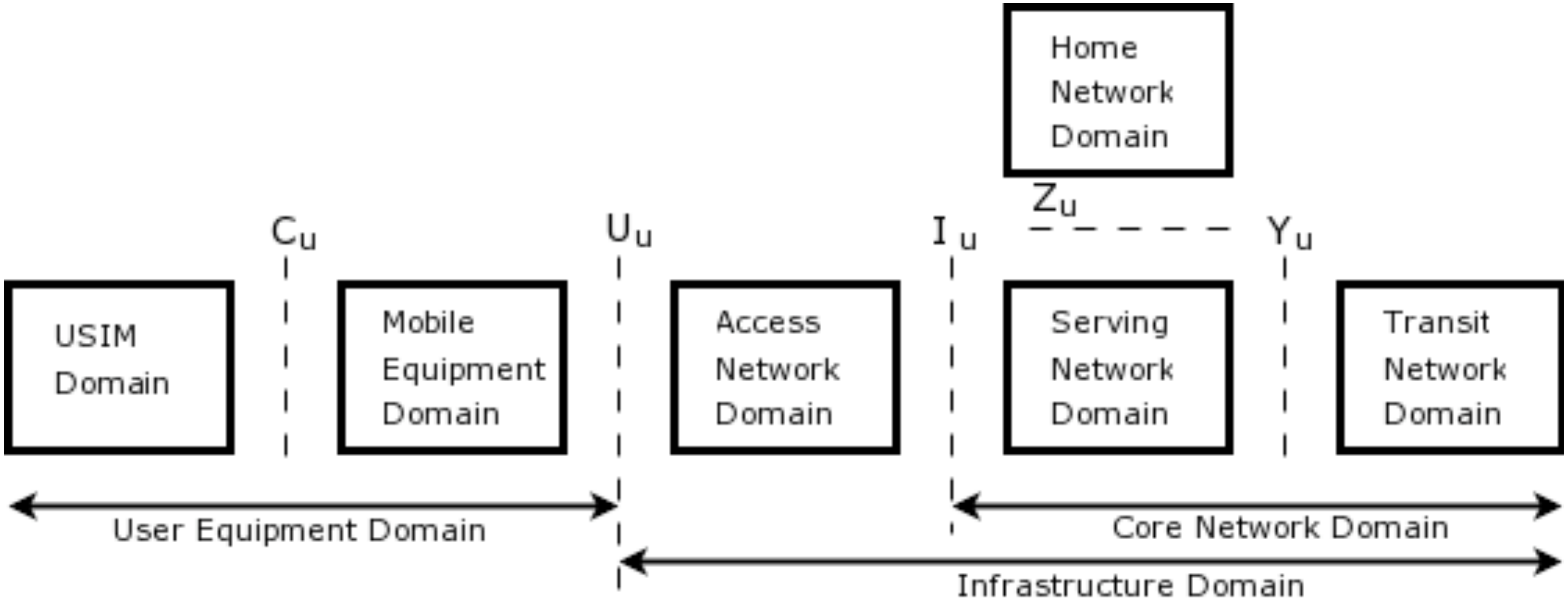


UMTS – history and planned standards

- Release 6
  - Extended location based services (LBS), with built in anonymization
  - Packet switches streaming services, with adaptation to available network resources (GERAN/GPRS, UTMS, WLAN)
  - Of course :-) DRM
  - Charging Management Framework (for extended payment systems)
  - For more see www.3gpp.org

UMTS network architecture and interfaces

- UTMS network architecture has several similarities to GSM, but you will find different names for some components
- As for GSM in UMTS several interfaces are defined
- UE – user equipment means more generally any UMTS enabled (mobile) device



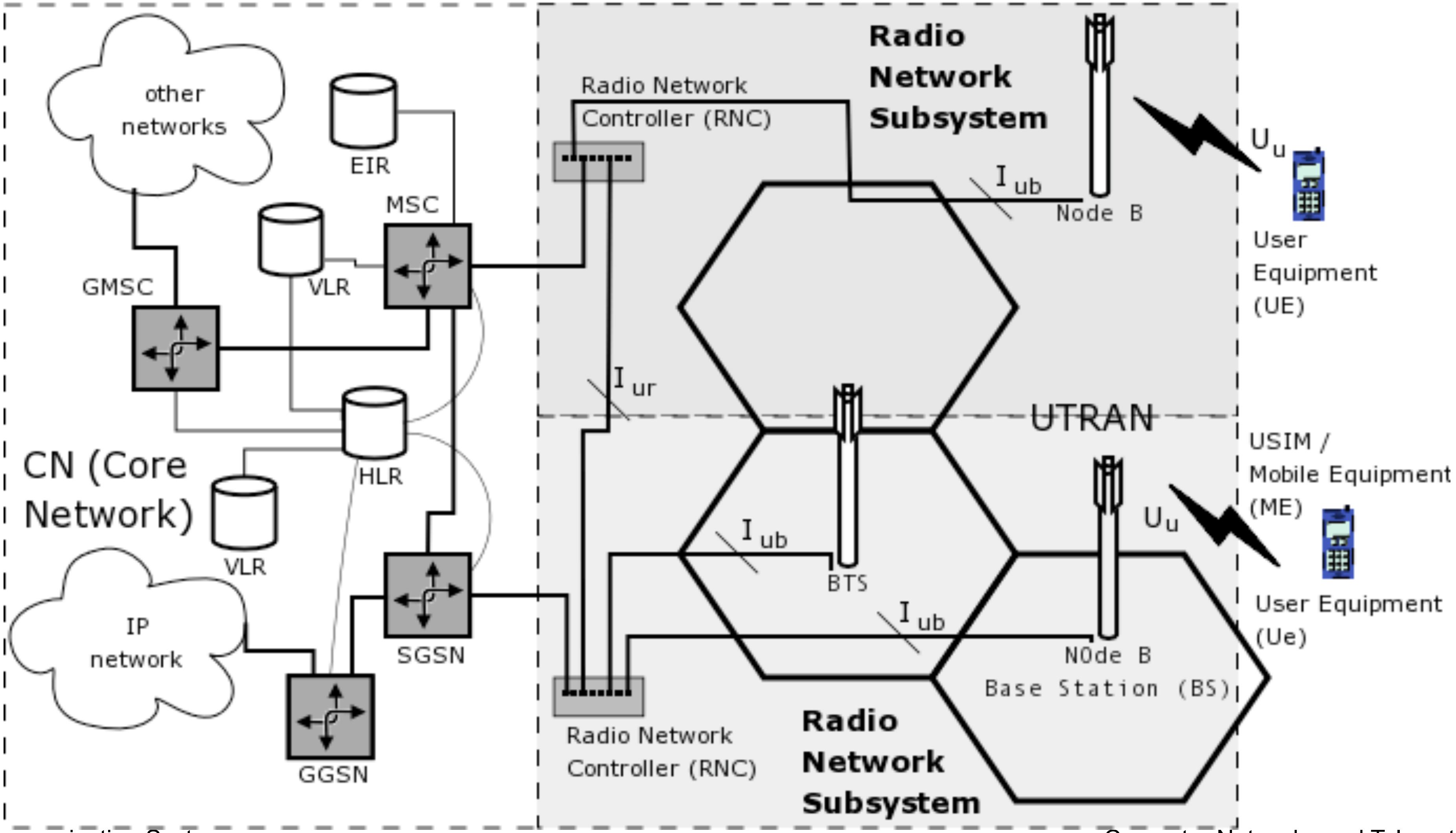
UMTS network domains

- 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

UMTS network domains - CN

- Infrastructure Domain
  - Shared between all users
  - Offers services to all authenticated users
- CN – Core Network the (mobile) telephony back-end infrastructure
  - Functions which are independent on access network
  - Handover between different systems
  - Location management if there is no dedicated link between UE and UTRAN
  - Inter-connection of different bearer networks

UMTS network architecture – Core Network, UTRAN, UE



UMTS network domains - CN

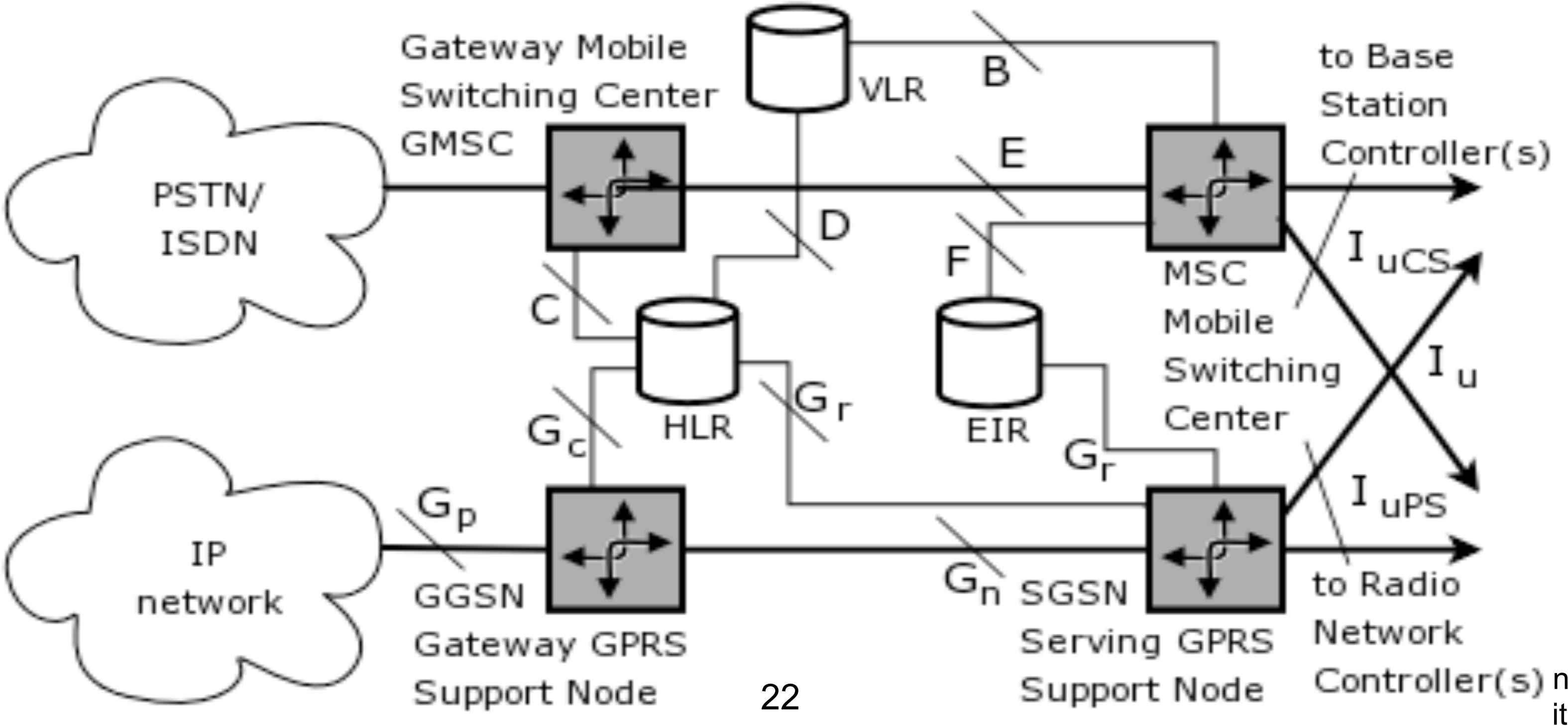
- CN infrastructure consists of
  - Serving network domain – network which actually provides the user access
  - Home network domain – functionality and information which is independent of actual user location
  - Transit network domain – infrastructure between several network components, different kind of networks and different network providers, operators

UMTS network domains - CN

- CN infrastructure split into two logical networks
  - Both may serve the two different radio networks via either BSC and RNS
  - Circuit switched domain (CSD)
    - IuCS interface
    - Traditional circuit switched data connection and signaling
    - Resource reservation on connection setup
    - GSM components (MSC, GMSC, HLR, VLR, EIR, ...)

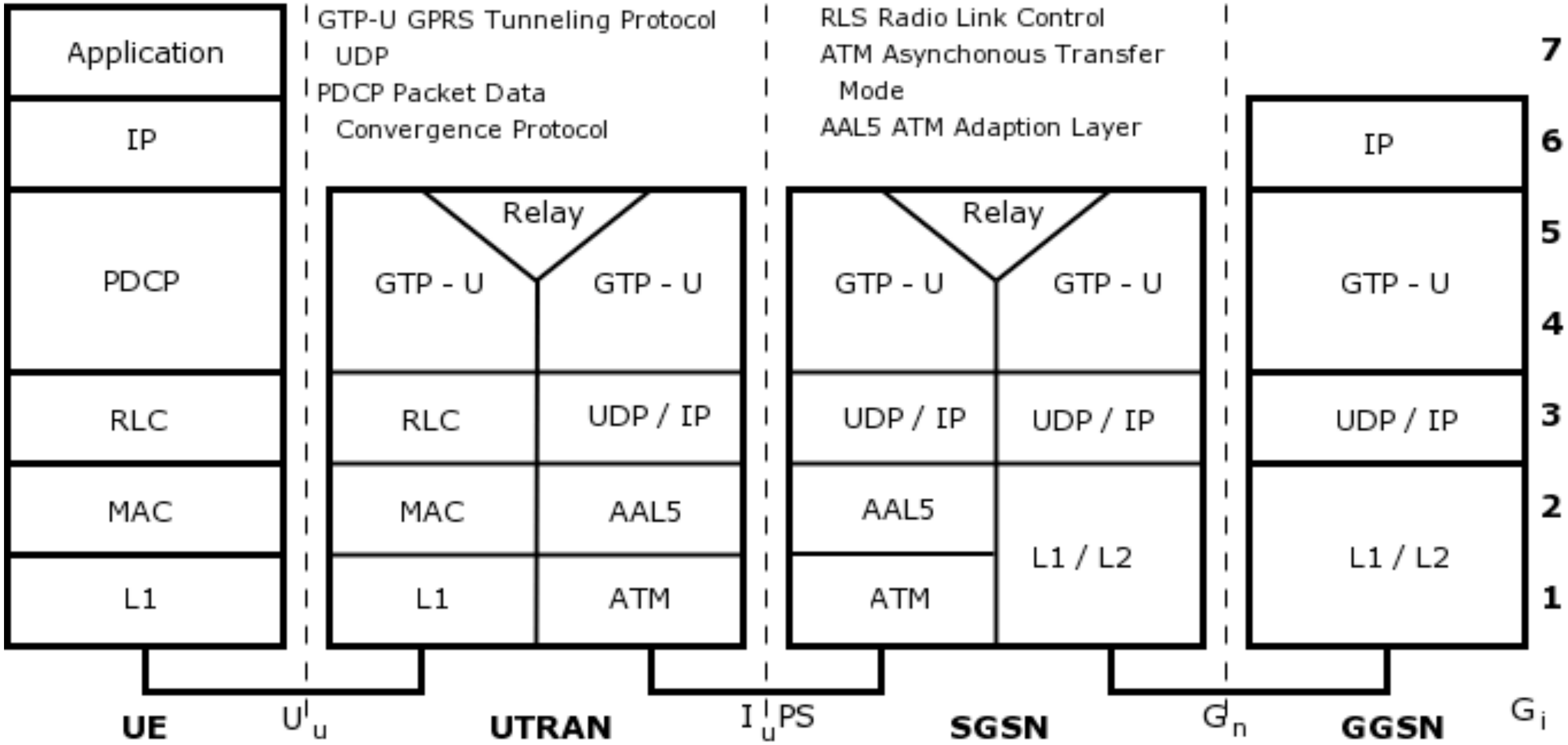
UMTS network domains - CN

- Packet switched domain (PSD)
  - IuPS interface
  - Packet orientated services
  - GPRS components (SGSN, GGSN)



UMTS network – packet switching domain

- The UTMS packet switching domain protocol stack follows the GPRS design

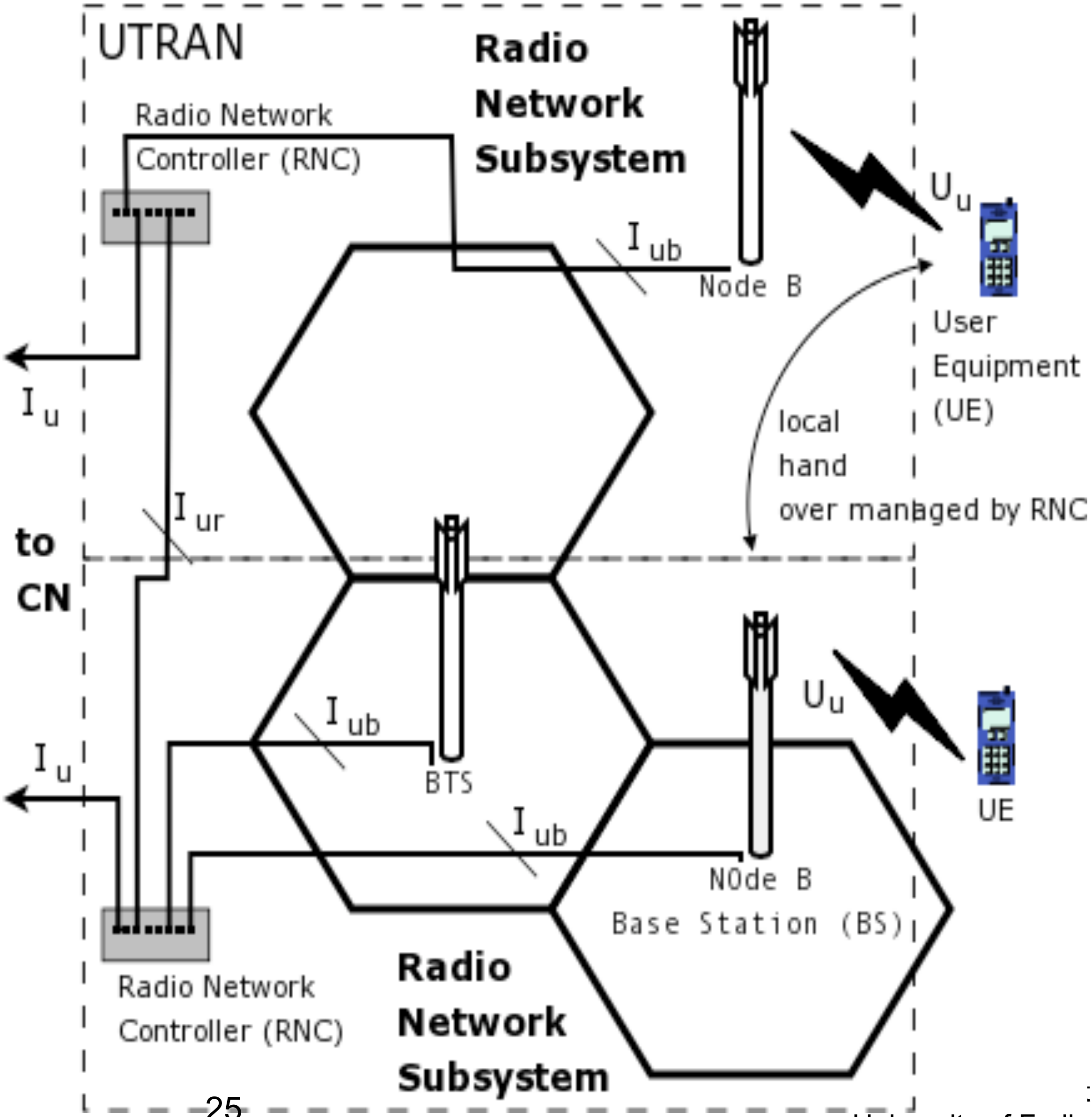


UMTS network - UTRAN

- UTRAN (UTRA network) is the UMTS transceiver radio interface network part
  - Manages mobility on cell level – handover decision
  - Composed of several Radio Network Subsystems (RNS) connected to the Core Network through the Iu interface
- Every Radio Network Subsystem is managed by Radio Network Controller (RNC)
  - RNC also handles radio resource management (RRM) operations
- RNC is responsible for the local handover process and the combining/multicasting functions related to macro diversity between different Node-Bs (Drift RNC - DRNC)

UTRAN - RNS

- RNSs can be directly interconnected through the Iur interface (interconnection of the RNCs)
- Node B may contain a single BTS or more than one (typically 3) controlled by a site controller



UMTS network - UTRAN

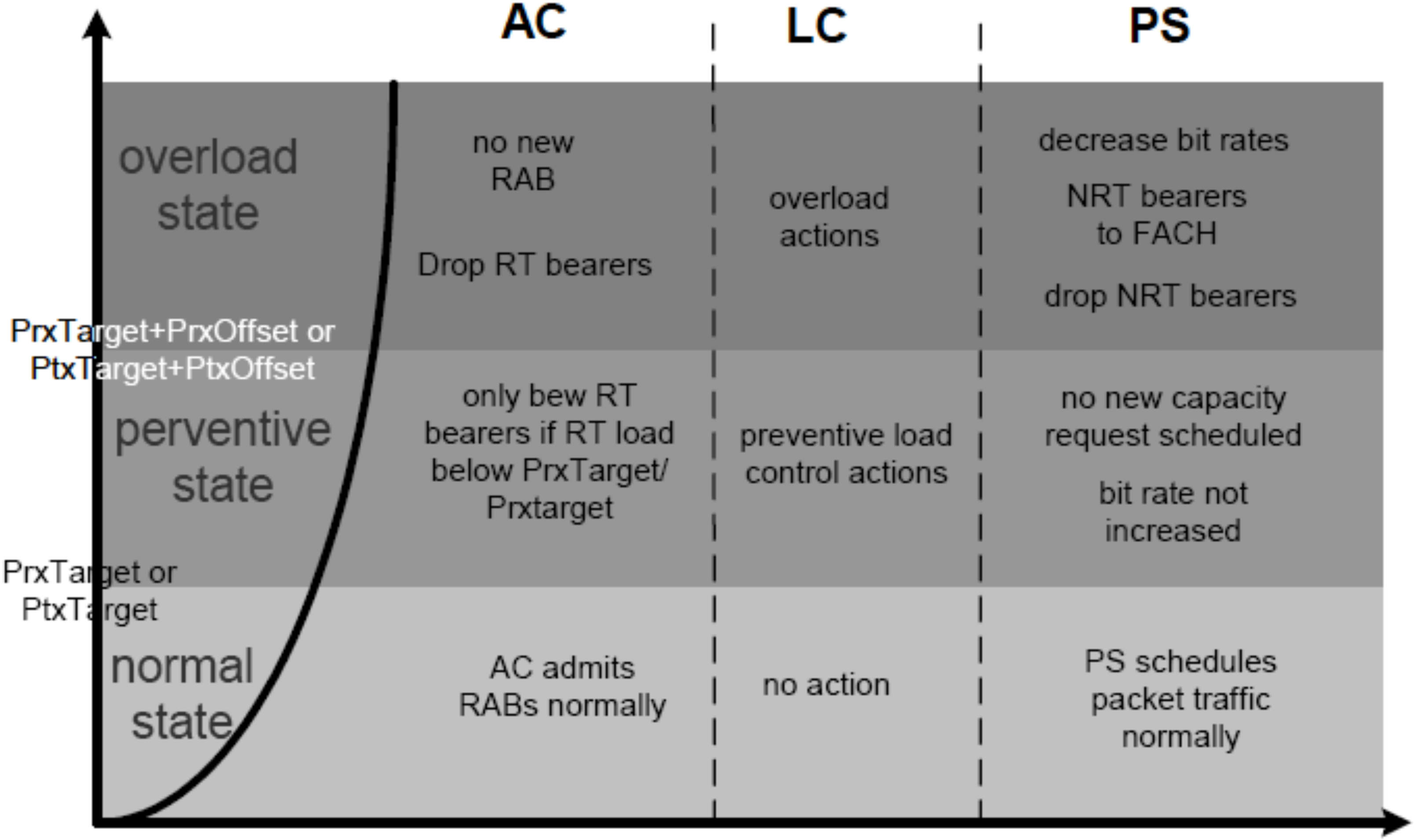
- UTRAN functions
  - Controls cell capacity and interference in order to provide an optimal utilization of the wireless interface resources
  - Includes Algorithms for Power Control, Handover, Packet Scheduling, Call Admission Control and Load Control
  - Encryption of the radio channel
  - Congestion control to handle situations of network overload
  - System information broadcasting
  - Micro and macro diversity (explained later)

UMTS network - UTRAN

- Network based functions
  - Packet Scheduling
    - Controls the UMTS packet access
    - Handles all non real time traffic, (packet data users)
    - Decides when a packet transmission is initiated and the bit rate to be used
  - Load Control
    - Ensures system stability and that the network does not enter an overload state
  - Admission control to avoid network overload
    - Decides whether or not a call is allowed to generate traffic in the network

UTRAN network function – Load Control

- Power Control



AC

LC

PS

overload state

no new RAB

Drop RT bearers

overload actions

decrease bit rates

NRT bearers to FACH

drop NRT bearers

PrxTarget+PrxOffset or PtxTarget+PtxOffset

perventive state

only bew RT bearers if RT load below PrxTarget/ Prxtarget

preventive load control actions

no new capacity request scheduled

bit rate not increased

PrxTarget or PtxTarget

normal state

AC admits RABs normally

no action

PS schedules packet traffic normally

UMTS network - UTRAN

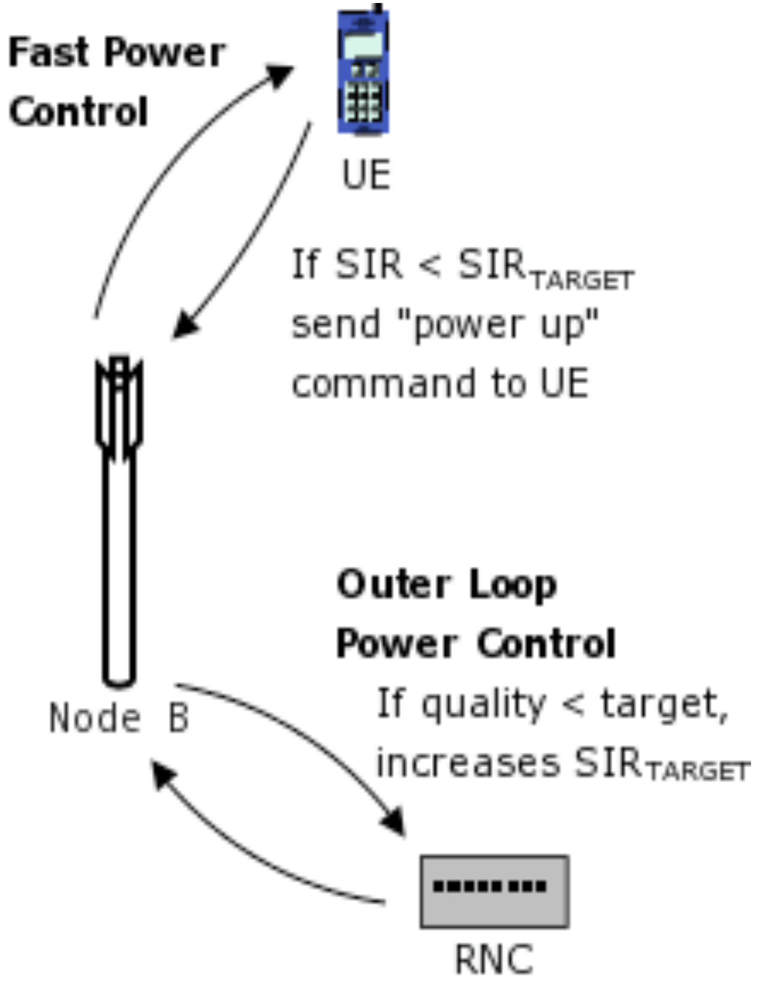
- Connection based functions
  - Power Control
    - Manages radio link quality - Uplink is handled per mobile (UE), downlink per physical channel
    - Ensures that transmission powers are kept at a minimum level and that there is adequate signal quality and level at the receiving end
  - Handover
    - guarantees user mobility in a mobile communications network
    - SRNS (Serving RNS) relocation

UTRAN - connection based functions

- Power Control handles
  - Setting of transmit power to keep QoS in required limits (regarding data rate, delay, BER, ...)
  - Path loss (near-far problem), shadowing (log-normal fading)
  - Fast fading (Rayleigh-, Rican-Fading)
  - Environment (delay spread, UE speed) which implies different performance of the de-interleaver and decoder
- Three types: Inner loop, outer loop (SIR-target adjusting), open loop (power allocation)
- Open-Loop Power Control
  - Rough estimation of path loss from receiving signal
  - Initial power setting, or when no feedback channel exist

UTRAN - connection based functions

- Closed-Loop Power Control
  - Feedback loop with 1.5kHz cycle to adjust uplink / downlink power to its minimum
  - Even faster than the speed of Rayleigh fading for moderate mobile speeds
- Outer Loop Power Control
  - Adjust the target SIR (Signal to Interference Ratio) setpoint in base station according to the target BER, commanded by RNC

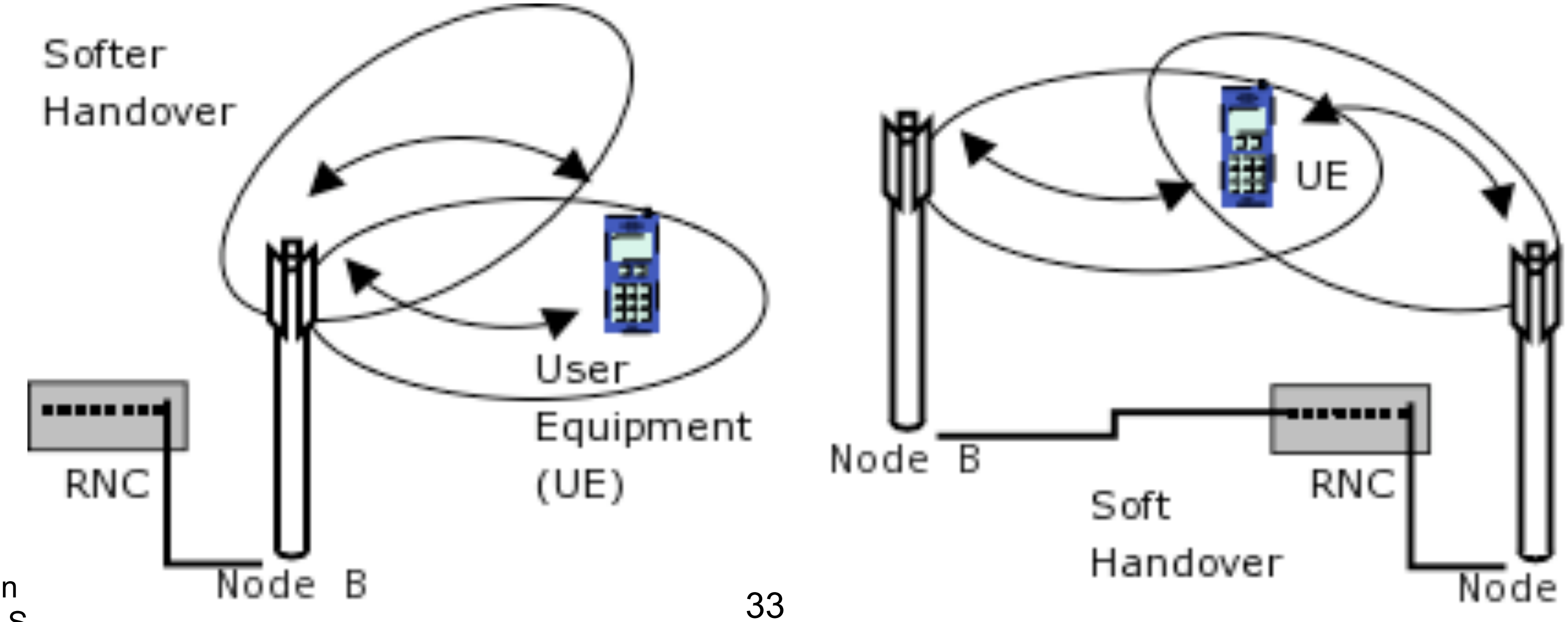

Fast Power Control
UE
If SIR < SIR_{TARGET} send "power up" command to UE
Node B
Outer Loop Power Control
If quality < target, increases SIR_{TARGET}
RNC

UTRAN - connection based functions

- UMTS provides several handover procedures
  - Intra Node B handover (softer)
  - Inter Node B handover, inter-frequency, intra-frequency (hard and soft)
  - Inter RNC (hard, soft and soft-softer)
  - Inter MSC
  - Inter SGSN
  - Inter System (UMTS - GSM)
- Hard Handover
  - Connection to a Node B is destroyed before a new one (to an other Node B is started)

UTRAN - connection based functions

- Soft Handover
  - A MS is in the overlapping coverage of 2 different base stations (Node B)
  - Concurrent communication via 2 air interface channels
  - Downlink: Maximal combining with rake receiver
  - Uplink: Routed to RNC for selection combining, according to a frame reliability indicator by the base station

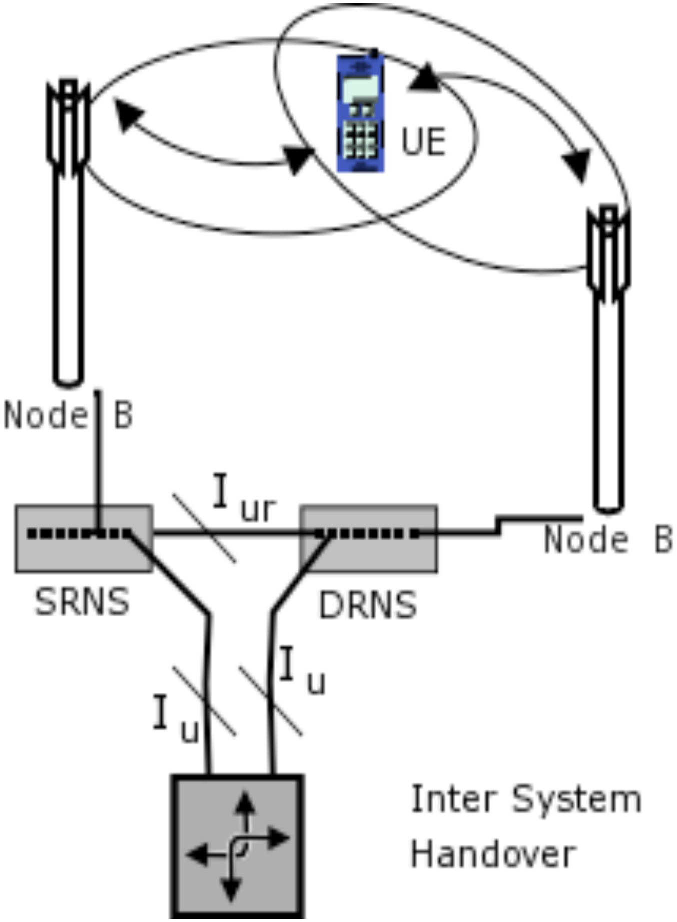


UTRAN - connection based functions

- Softer Handover
  - A MS is in the overlapping coverage of 2 sectors of a base station
  - Concurrent communication via 2 air interface channels
  - 2 channels are maximally combined with rake receiver
- Soft Softer Handover
  - Soft and softer handover combined
- Inter system handover from UMTS to GSM or vice versa
  - RNS the UE is connected to is the Serving RNS
  - RNS which provides additional resources, e.g for handover procedure is Drift RNS

UTRAN - connection based functions

- Network crossing handovers
  - End-to-end connection between UE and CN is handled over the Iu interface of the SRNS (Serving Radio Network Subsystem)
  - Exchange of SRNS will lead to change of Iu
  - Initiated by SRNS
  - Handled by RNC and CN



UTRAN – Base Stations (Node B) – Radio Interface

- Base Station – Node B
  - Mainly handles physical layer tasks
  - Main task of node B is to establish the physical implementation of the Uu interface (communication with the UE) and the implementation of Iub interface (Communication with the RNC)
  - Providing the Uu interface means that the Base Station implements WCDMA radio access Physical Channels and transfer information from Transport Channels to the Physical Channels based on arrangements determined by the RNC
  - The term Physical Channels means different kinds of bandwidth allocated for different purposes over Uu interface

UMTS - Air Interface

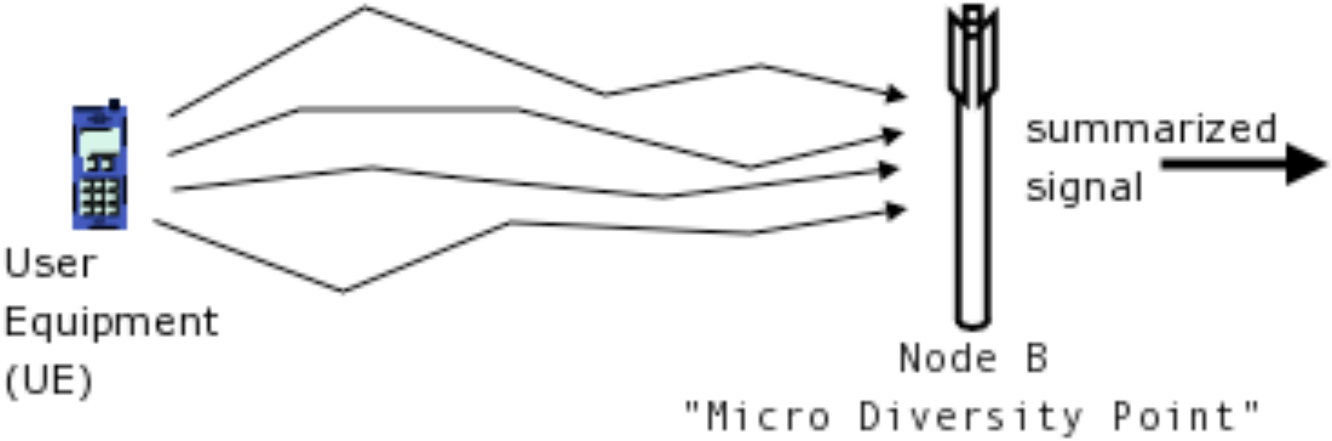
- UTMS uses Wideband CDMA (Code Division Multiple Access) on two different duplex mechanisms
- CDMA allows frequency reuse factor of 1 (GSM 4 ... 18)
  - 5MHz Bandwidth allows multipath diversity using „Rake Receiver“
  - Variable Spreading Factor (VSF) to offer Bandwidth on Demand (BoD) up to 2MHz
  - Fast (1.5kHz) Power Control for Optimal Interference Reduction
- Services multiplexing with different QoS
- Real-time / Best-effort
  - 10% Frame Error Rate to 10-6 Bit Error Rate

UMTS – QoS classes

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

UMTS – Rake Receiver

- Radio receiver designed to counter the effects of multipath fading
  - rake receiver is so named because of its analogous function to a garden rake, each finger collecting bit or symbol energy similarly to how tines on a rake collect leaves
  - Commonly used in a wide variety of CDMA and W-CDMA radio devices

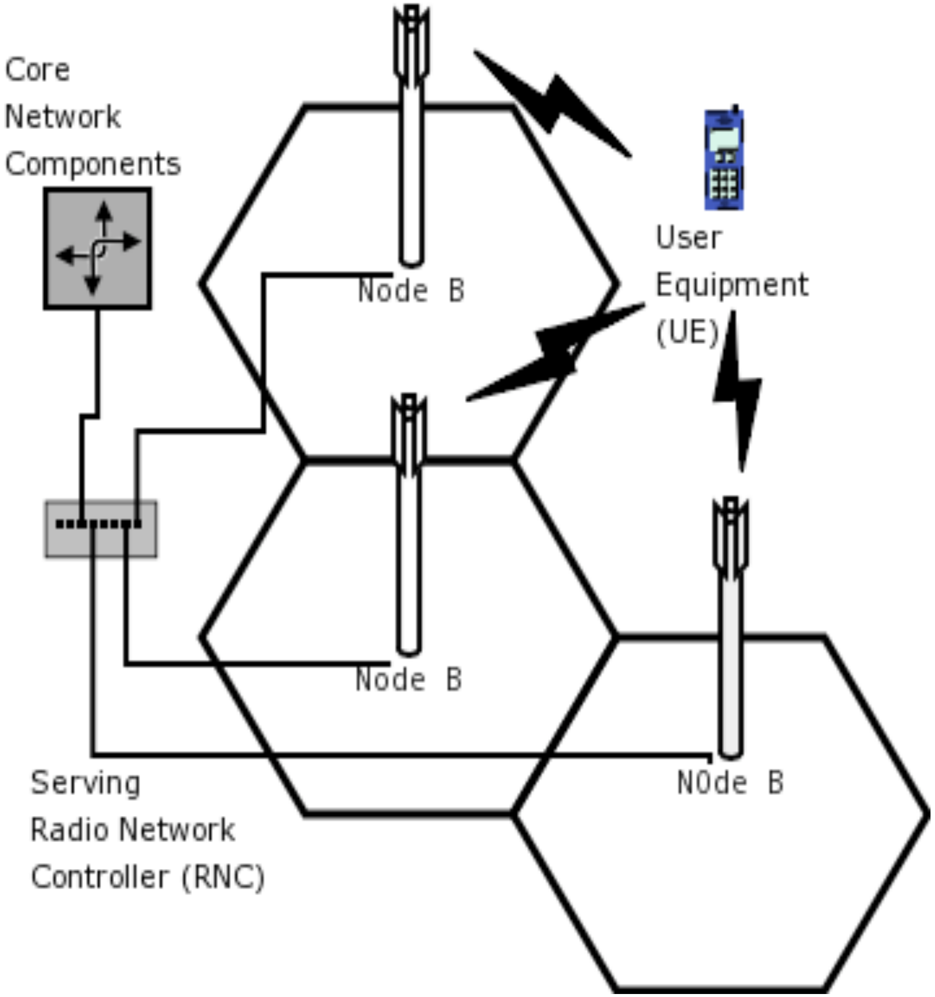


UMTS – Rake Receiver

- Radio receiver
  - Uses several "sub-receivers" each delayed slightly in order to tune in to the individual multipath components
  - Each component decoded independently, but at a later stage combined in order to make the most use of the different transmission characteristics of each path
  - Results in higher Signal-to-noise ratio (or Eb/No) in a multipath environment than in a "clean" environment
  - Multipath fading is a common problem in wireless networks especially in metropoletan areas
- Another “trick” to increase connection quality and reliability is macro diversity

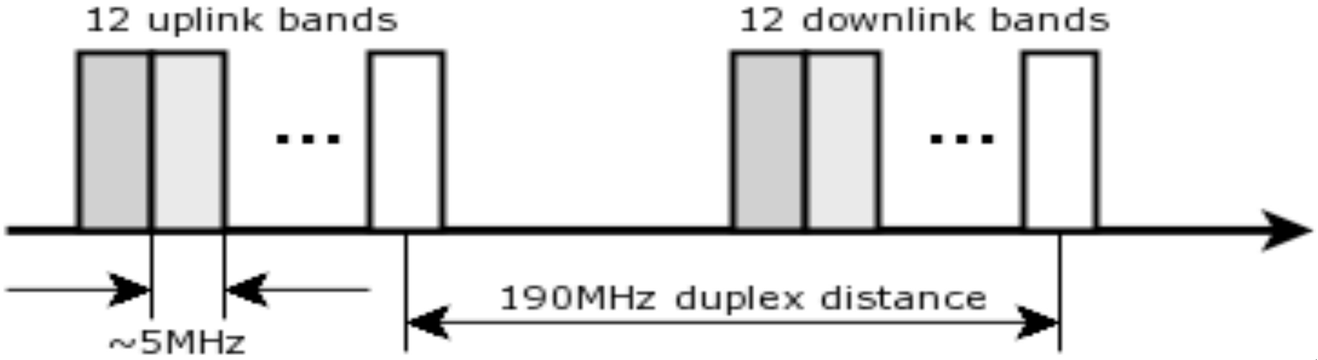
UMTS – Macro Diversity

- Same data stream is sent over different physical channels
- Uplink – UE sends its data to different Node B
- Data stream is reassembled, reconstructed in Node B, SRNC or NC
- Downlink – receiving same data from different cells on different spread codes



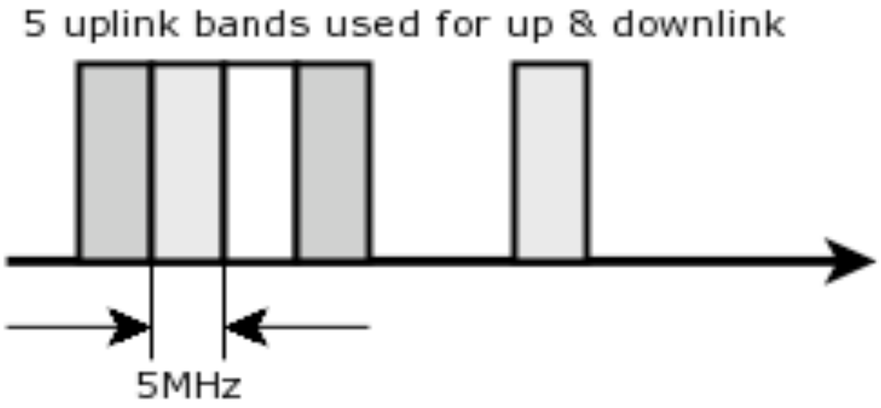
UMTS - Air Interface

- UMTS FDD (Frequency Division Duplex)
  - Uplink: 1920 - 1975 MHz
  - Downlink: 2110 - 2165 MHz
  - 190 MHz duplex distance
  - ca. 5MHz (variable) carrier spacing (DS CDMA – Direct Sequence CDMA)
  - 12 bands in uplink & downlink



UMTS - Air Interface

- UMTS TDD (Time Division Duplex)
- Uplink & Downlink: 1900 - 1920 MHz and 2020 - 2025 MHz
  - 5 carriers in total, 15 timeslots per frame
  - a user may use one or several timeslots
  - a timeslot can be assigned to either uplink or downlink



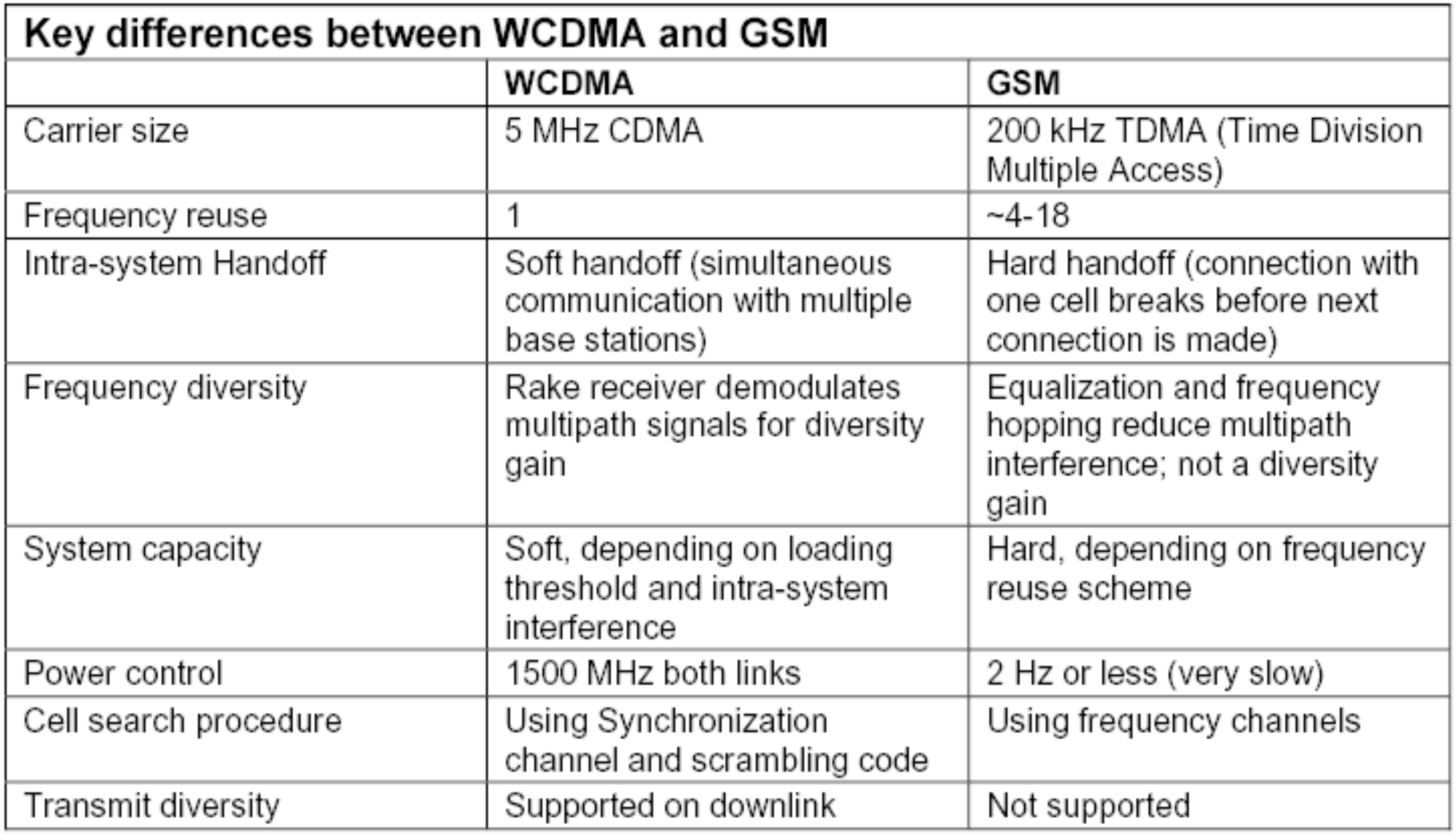
UMTS – Cell Breathing

- Advantages of UMTS W-CDMA
  - Power Control - solves the near-far problem
- Soft capacity, dynamic cell sizes
  - Different to GSM, where
    - fixed cell size
    - Number of logged in users has no influence on cell size
- In UMTS cell size is tightly interrelated with its capacity
  - Size depends on signal/noise ratio because of both maximum TX power and number of active users (interference in the same cell through other users and with other cells) which results in cell breathing

UMTS – Cell Breathing

- Interference increases noise in signal
  - UE on the cell edge is transmitting with max power
  - Another UE becomes active – results in increased interference
  - The received signal from the UE on the cell edge is too weak and communication becomes impossible
  - Restriction of participants needed
  - Effective cell size decreases with increasing number of users
  - There is a trade-off between capacity and coverage
  - Results in cell breathing and imposes greater difficulties on network planning

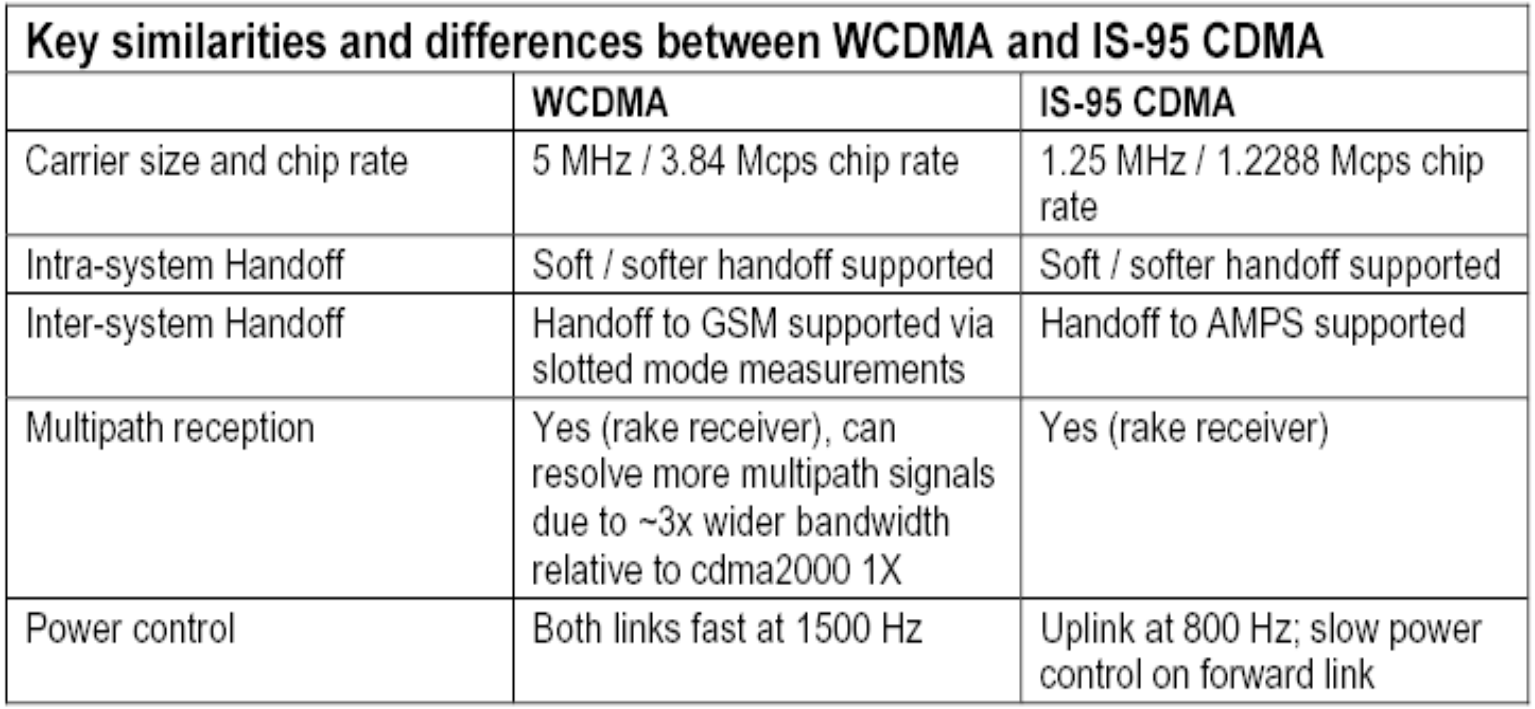
Differences and similarities of GSM and UMTS



Key differences between WCDMA and GSM

	WCDMA	GSM
Carrier size	5 MHz CDMA	200 kHz TDMA (Time Division Multiple Access)
Frequency reuse	1	~4-18
Intra-system Handoff	Soft handoff (simultaneous communication with multiple base stations)	Hard handoff (connection with one cell breaks before next connection is made)
Frequency diversity	Rake receiver demodulates multipath signals for diversity gain	Equalization and frequency hopping reduce multipath interference; not a diversity gain
System capacity	Soft, depending on loading threshold and intra-system interference	Hard, depending on frequency reuse scheme
Power control	1500 MHz both links	2 Hz or less (very slow)
Cell search procedure	Using Synchronization channel and scrambling code	Using frequency channels
Transmit diversity	Supported on downlink	Not supported

Differences and similarities of GSM and UMTS



Key similarities and differences between WCDMA and IS-95 CDMA

	WCDMA	**IS-95 CDMA**
Carrier size and chip rate	5 MHz / 3.84 Mcps chip rate	1.25 MHz / 1.2288 Mcps chip rate
Intra-system Handoff	Soft / softer handoff supported	Soft / softer handoff supported
Inter-system Handoff	Handoff to GSM supported via slotted mode measurements	Handoff to AMPS supported
Multipath reception	Yes (rake receiver), can resolve more multipath signals due to ~3x wider bandwidth relative to cdma2000 1X	Yes (rake receiver)
Power control	Both links fast at 1500 Hz	Uplink at 800 Hz; slow power control on forward link

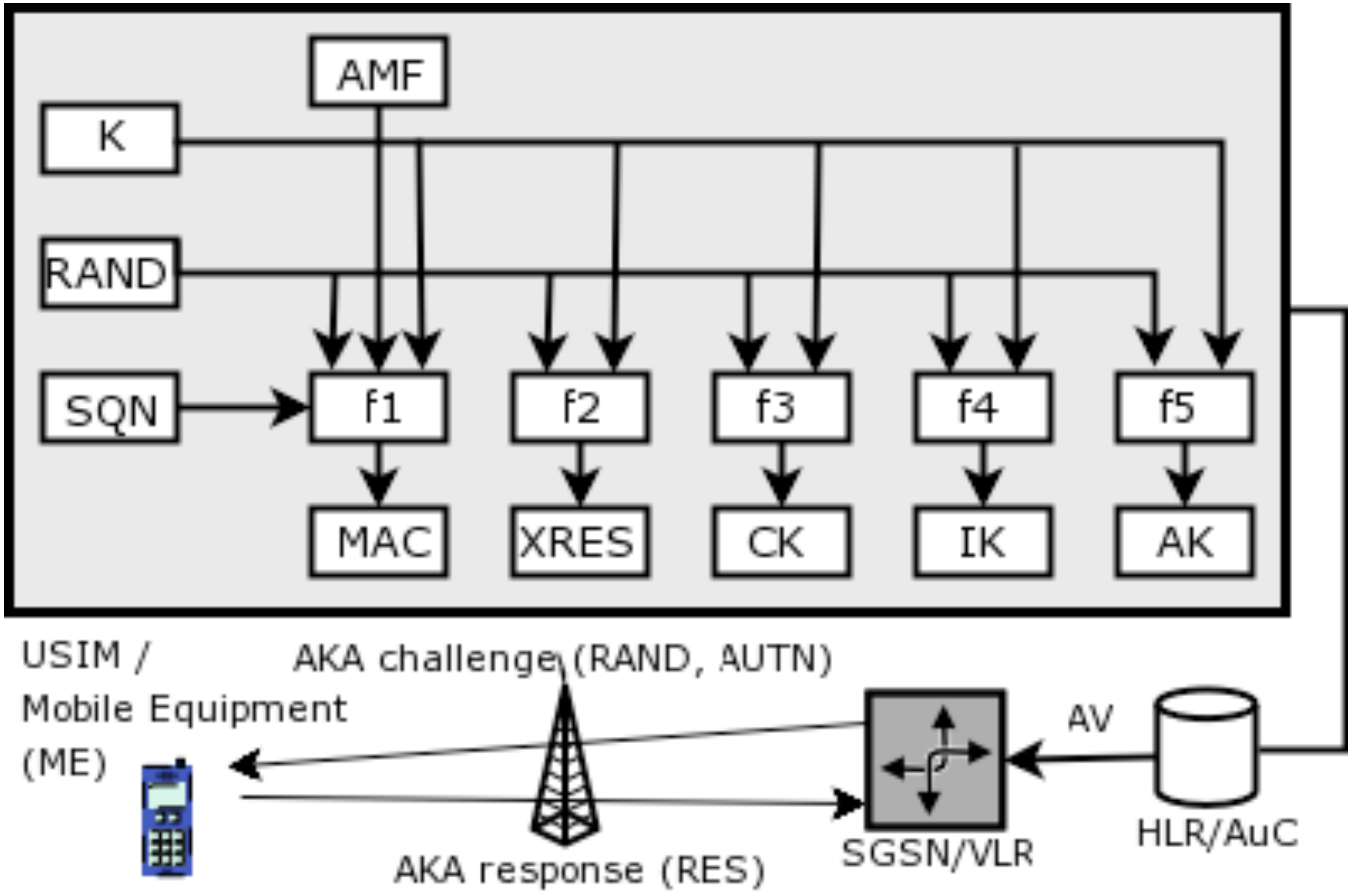
UMTS – the physical layer

- After introduction of physical layer components (Node B) and principles (rake receiver and macro diversity)
- Explanation of the Code Division Multiple Access
    - “Chips” instead of combined TDM, FDM
    - TDD and FDD frame structure
    - ...

UMTS - WCDMA

- UTMS uses two methods for Terrestrial Radio Access: Frequency Division Duplex of two paired 5MHz bands
  - Wideband CDMA
  - Channels are divided via frequency distribution
- Time Division Duplex
  - A single 5MHz frequency band
  - Alternating
  - WCDMA and TDMA as multiplexing method4

UMTS – security and authentication



UMTS – 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

UMTS – security and authentication

- Functions for authentication and key agreement (AKA)
  - f_1: computation of MAC (Message Auth. Code)
  - f_2: computation of MAC, probably shortened
  - f_3, f_4, f_5: computation of a key from a random number
  - $\otimes$ XOR, || concatenation
- Generation of AV (within HLR/AuC)
  - Generation of random Sequence Number (SEQ, once at the beginning)
  - Generation of random challenge RAND (per AV)
  - AMF (Authentication Key Management Field) to distinguish several different algorithms

UMTS – security and authentication

- Computation of the several values (within HLR/AuC)
  - MAC=f1 (SQN || RAND || AMF)
  - XRES=f2 (RAND)
  - CK=f3 (RAND)
  - IK=f4 (RAND)
  - AK=f5 (RAND) , anonymity key to anonymize SQN
  - AUTN= ((SQN $\otimes$ AK) || AMF || MAC)
  - AV= (RAND || XRES || CK || IK || AUTN)

UMTS – security and authentication

- Computation of the several values (within USIM)
  - Reception of RAND and AUTN from VLR or SGSN
  - AK=f_5 (RAND)
  - SQN=(SQN $\otimes$ AK) $\otimes$ AK
  - XMAC=f_1 (SQN || RAND || AMF) (eXpected MAC)
  - Comparison of XMAC and MAC (from AUTN)
    - If this procedure fails the authentication of network does not succeed and the UE sees the cell as forbidden
  - Check if sequence number is from the expected range
  - RES=f_2 (RAND)

UMTS – security and authentication

- Computation of the several values (within USIM, cont.)
  - Send response to VLR or SGSN with RES
  - CK=f_3 (RAND
  - IK=f_4 (RAND)
  - IK, CK used for RLC encryption
- Operation within VLR or SGSN
  - Reception of RES from the USIM
  - Comparison of RES with XRES (eXpected RES, from AV sent by HLR/AuC)
    - If not equal user authentication failed

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