UMTS Terrestrial Radio Access Network (UTRAN)

- UMTS Terrestrial Radio Access (UTRA)
- UTRAN Architecture and Protocols
- UTRAN Procedures (see separate presentation)
Important References

Books:

- Kaaranen, Ahtiainen, Laitinen, Naghian, Niemi: UMTS Networks – Architecture, Mobility and Services. 2nd edition, Wiley, 2005

Central 3GPP Documents on UTRAN:

- 25.401: UTRAN overview
- 25.301: Radio link protocols (UTRA)
- 25.931: UTRAN procedures
UTRAN Architecture

- Components and Interfaces
- Macro Diversity
- UTRAN Functions
- Protocol Architecture
- RRC connection and signaling connection
- Access Stratum and Non Access Stratum
A Radio Network Subsystem (RNS) consists of a RNC, one or more Node B’s and optionally one SAS (standalone A-GPS serving mobile location center)

Source: 3GPP 25.401
Macro Diversity: Serving and Drift RNS

Each RNS is responsible for the resources of its set of cells.

For each connection between User Equipment (UE) and the UTRAN, one RNS is the Serving RNS (SRNS).

Drift RNSs (DRNS) support the Serving RNS by providing radio resources.

Macro-diversity and handover is supported by Node B and RNC.
Serving, Drift and Controlling RNC

Softer handover:
maximum ratio combining
in Node B

Soft handover:
radio frame selection (layer 1)
in SRNC (and DRNC)
Roles of RNSs/RNCs

Source: 3GPP 21.905

Serving RNS (SRNS)
- A role an RNS can take with respect to a specific connection between a UE and UTRAN
- There is one Serving RNS for each UE that has a connection to UTRAN
- The Serving RNS is in charge of the RRC connection between a UE and the UTRAN
- The Serving RNS terminates the Iu for this UE

Drift RNS (DRNS)
- A role an RNS can take with respect to a specific connection between a UE and UTRAN
- An RNS that supports the Serving RNS with radio resources when the connection between the UTRAN and the UE need to use cell(s) controlled by this RNS

Controlling RNC (CRNC)
- A role an RNC can take with respect to a specific set of UTRAN access points (an UTRAN access point is specific to a cell)
- Exactly one Controlling RNC serves an UTRAN access point (i.e. each cell)
- The Controlling RNC has the overall control of the logical resources of its UTRAN access points
Distribution of Functions between RNCs

Radio resource management:

- CRNC owns the radio resources of a cell
- SRNC handles the connection (RRC/RANAP) to one UE, and may borrow radio resources of a certain cell from the CRNC
- SRNC performs dynamical control of power for dedicated channels, within limits admitted by CRNC
  - Inner loop power control for some radio links of the UE connection may be done by the Node B
  - Inner loop control is controlled by an outer loop, for which the SRNC has overall responsibility
- SRNC handles scheduling of data for dedicated channels
- CRNC handles scheduling of data for common channels (no macro diversity on DL common channels)

Source: 3GPP 25.401, Ch 6.3
Serving, Drift and Controlling RNC

- Core Network
  - UTRAN
  - RNS
  - DRNC
  - SRNC
  - Node B

- Iu
- Iur
- Iub

- UE 1
- UE 2

- Common/shared channel
- Dedicated channel in macro-diversity mode
Serving and Controlling RNC
Example: DCH (UL&DL macro diversity)

Combining/splitting is supported for DCH only
(no layer 2 processing in Node B and DRNC)

Source: 3GPP 25.401, sc 11.2.4 (see also 25.301, sc 5.6.1)
Serving and Controlling RNC
Example: FACH (DL, no macro diversity)

Physical channel is terminated within node B (no support for combining/splitting)

Common MAC (MAC-c/sh) terminates in the CRNC

Dedicated MAC (MAC-d) terminates in the SRNC

Source: 3GPP 25.401, sc 11.2.3 (see also 25.301, sc 5.6.2)
Example: BCH

RRC terminates in
- **CRNC**: provides broadcast information distributed by node B
- **Node B**: handles periodic repetition of broadcast information

Splitting of RRC eliminates repetition of broadcast data on Iub interface

Source: 3GPP 25.301, sc 5.6.7
UTRAN Architecture: Functional Split

**Control plane**
- CRNC/DRNC
  - Cell Control
  - Paging
  - Broadcast
  - Com./Shared Channel Processing

**Bearer plane**
- SRNC
  - Mobile Control
  - Dedicated Channel Processing

**Core Network**

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UTMS Networks
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UTRAN Protocol Architecture: Summary

Core Network

Node-B
- RRC-b
- RLC-b
- MAC-b
- PHY
- Soft Handover Splitting / Combining

CRNC DRNC
- N B A P
- RRC-b
- RLC-b
- MAC-b
- PHY
- Soft Handover Splitting / Combining

RANAP
- SABP
- BM-IWF
- RRC-c/sh
- RLC-c/sh
- MAC-c/sh
- PCH
- RACH
- FACH
- DSCH
- CPCH
- Optional

SRNC
- RANAP
- Iu-PS FP
- Iu-CS FP
- RRC-d
- PDCP
- RLC-d
- MAC-d
- DCCH
- DTCH
- DCH

Soft Handover Splitting / Combining

User plane
Control plane
UTRAN Architecture Principles – User Plane

Non-Access Stratum:
- Protocols between UE and CN that are not terminated in the UTRAN

Access Stratum:
- Provides UE-CN transport service to NAS services
- AS protocols are closely linked to radio technology

Source: 3GPP 25.401
UTRAN Architecture Principles – Control Plane

NAS control plane functions:
- CM: Connection Management
- MM: Mobility Management
- GMM: GPRS MM
- SM: Session Management

Source: 3GPP 25.401
UTRAN Functions (1)

- Transfer of User Data
- Functions related to overall system access control
  - Admission Control
  - Congestion Control
  - System information broadcasting
- Radio channel ciphering and deciphering
- Integrity protection
- Functions related to mobility
  - Handover
  - SRNS Relocation
  - Paging support
  - Positioning
- Synchronisation

Source: 3GPP 25.401, Ch 7.1
UTRAN Functions (2)

- Functions related to radio resource management and control
  - Radio resource configuration and operation
  - Radio environment survey
  - Combining/splitting control
  - Connection set-up and release
  - Allocation and deallocation of radio bearers
  - Radio protocols function
  - RF power control
  - Radio channel coding and decoding
  - Channel coding control
  - Initial (random) access detection and handling
  - CN distribution function for Non Access Stratum messages

- Functions related to broadcast and multicast services (broadcast/multicast interworking function BM-IWF)
  - Broadcast/Multicast Information Distribution
  - Broadcast/Multicast Flow Control
  - Cell-based Services (CBS) Status Reporting

- Tracing
- Volume reporting
Wrap-up: Why is UTRAN so complicated?

Some answers:

• Limitation of radio resources and last-mile transport resources

• CDMA macro-diversity mode
  – Single RLC/MAC entity required for synchronous delivery of radio frames over all SHO legs
  – Splitting/combining of radio frames (multicast)

• Tight handover requirements esp. for voice
  – Need for proactive handover initiation requires interaction between radio layers

• Designed for maximum functionality and flexibility
  – Overdimensioned from the viewpoint of a single application
Modes and states (PS mode)

- **SM: PDP context** (active, inactive)
- **PMM state** (detached, idle, connected)
- **Signaling connection**
- **RRC connection**
- **UE mode**

**Network Elements**:
- **UE**
- **SGSN**
- **GGSN**
- **HLR**
- **RNC**
Radio Link, RRC Connection, Signaling Connection

RRC connections and signaling connections are logical links
Radio Link, RRC Connection, Signaling Connection

Core Network

UTRAN

RNS

DRNC

Node B

Node B

Iu

Iub

Iur

RNC

SRNG

Node B

Node B

Iub

Iub

Iub

signaling connection

RRC connection

radio link

UE
RRC Connection and Signaling Connection

UE
Higher layer control

RRC

Signaling Radio Bearer

RRC Connection

SRNC

RRC

RANA P

Iu Signaling Bearer

RANAP Connection

MSC/ VLR or SGSN
Higher layer control

RANA P

Radio Access Bearer

Signaling Connection
RRC Connection

- RRC state machine exists as two peer entities, one in the MS and one in UTRAN (SRNC)
- Apart from transient situations and error cases the two peer entities are synchronized

UTRAN Registration Area (URA):
- area covered by a number of cells
- URA is only internally known in the UTRAN

Diagram:
- Connected mode
  - Cell Connected
  - Enter URA connected state
  - Enter cell connected state
- Connected mode
  - URA Connected
- RRC connection establishment
- RRC connection release
- Idle mode
Signaling Connection

• No signaling connection exist (idle state)
  – UE has no relation to UTRAN, only to CN
  – no data transfer
  – paging identification by IMSI, TMSI, P-TMSI

• Signaling connection exist (connected state)
  UE position can be known on different levels:

  - **URA level** (UTRAN registration area): URA is a specified set of cells, which can be identified on the BCCH.

  - **Cell level**: Different channel types can be used for data transfer:
    - Common transport channels (RACH, FACH, DSCH, USCH)
    - Dedicated transport channels (DCH)

Source: 3GPP 25.301, ch 6.2
Important Vocabulary

Source: 3GPP 21.905

**RRC connection**
- point-to-point bi-directional connection between RRC peer entities on the UE and the UTRAN sides
- UE has either zero or one RRC connection

**Signaling connection**
- an acknowledged-mode link between the UE and the CN to transfer higher layer information between the entities in the non-access stratum (via RRC and RANAP)

**Radio link**
- a logical association between a single UE and a single UTRAN access point (cell)
- its physical realization comprises one or more radio bearer transmissions

**Radio bearer** (compare signaling radio bearer)
- service provided by the RLC layer for transfer of user data between UE and SRNC

**Radio interface**
- interface between UE and a UTRAN access point
- radio interface encompasses all the functionality required to maintain the interface
Radio Interface Protocols
UMTS Terrestrial Radio Access (UTRA)

- Air interface protocol architecture
- Layer 1, 2 and 3 protocols
- Mapping between logical, transport and physical channels
Radio Protocols – Overview

Layer 3
- IP, PPP (user plane)
- RRC (control plane)

Layer 2
- PDCP (user plane)
- BMC (user plane)
- RLC
- MAC

Layer 1
- PHY

See 3GPP 25.301 and UMTS Networks book, ch. 9
Physical Layer – Services

Physical layer offers information transfer services (transport channels) to MAC and higher layers.

Physical layer transport services define

- how and

- with what characteristics data are transferred over the radio interface.

Transport channels do not define what is transported (which is defined by logical channels).

Example: DCH offers the same type of service for control and user traffic.
Physical Layer – Channel Types

- **common transport channels** (there is a need for inband identification of the UEs when particular UEs are addressed)
- **dedicated transport channels** (the UEs are identified by the physical channel, i.e. code and frequency for FDD (code, time slot and frequency for TDD))
Physical Layer – Common Transport Channels (1)

Random Access Channel (RACH)

- Contention based uplink channel used for transmission of relatively small amounts of data, e.g. for initial access or non-real-time dedicated control or traffic data

Forward Access Channel (FACH)

- Common downlink channel for relatively small amount of data
- no closed-loop power control

Downlink Shared Channel (DSCH) - TDD only

- Downlink channel shared by several UEs carrying dedicated control or traffic data

Uplink Shared Channel (USCH) - TDD only

- Uplink channel shared by several UEs carrying dedicated control or traffic data
Physical Layer – Common Transport Channels (2)

Broadcast Channel (BCH)

- Downlink channel used for broadcast of system information into an entire cell

Paging Channel (PCH)

- A downlink channel used for broadcast of control information into an entire cell allowing efficient UE sleep mode procedures
- Currently identified information types are paging and notification
- Another use could be UTRAN notification of change of BCCH information

High-Speed Downlink Shared Channel (HS-DSCH) – Rel. 5

- High-speed downlink channel shared by several UEs
Physical Layer – Dedicated Transport Channels & Transport Formats

**Dedicated Channel (DCH)**
Channel dedicated to one UE used in uplink or downlink

**Enhanced Dedicated Channel (E-DCH)**
- Channel dedicated to one UE used in uplink only.
- Subject to Node-B controlled scheduling and HARQ

**Transport Formats and Transport Format Sets**
- A **Transport Format** or a **Transport Format Set** is associated with each transport channel
- A Transport Format defines the format offered by L1 to MAC (encodings, interleaving, bit rate and mapping onto physical channels)
- A **Transport Format Set** is a set of Transport Formats
- Example: a variable rate DCH has a Transport Format Set (one Transport Format for each rate), whereas a fixed rate DCH has a single Transport Format

See 3GPP 25.302, ch. 7 and Walke, ch 5.10, for details on Transport Formats and Transport Format Sets
Physical Layer Processing

**Note:** Functional blocks which implement concatenation, segmentation, interleaving, discontinuous transmission (DTX) and macrodiversity distribution/combining have been suppressed.

**Note:** Physical Channel Mapping is used to implement multicoding (more than one DPCH). This will usually only be used for high data rates.

See 3GPP 25.302 for details.
Physical Layer – Functions

- Macrodiversity distribution/combining and soft handover execution
- Error detection on transport channels and indication to higher layers (CRC)
- FEC encoding/decoding and interleaving/deinterleaving of transport channels
- Multiplexing of transport channels and demultiplexing of coded composite transport channels
- Rate matching (fit bits into physical channel)
- Mapping of coded composite transport channel on multiple physical channels
- Power weighting and combining of physical channels
- Modulation and spreading/demodulation and despreading of physical channels
- Frequency and time (chip, bit, slot, frame) synchronisation
- Measurements and indication to higher layers (e.g. frame error rate, signal-to-interference ratio, interference power, transmit power, etc.)
- Closed-loop power control
- RF processing
- Support of timing advance on uplink channels (TDD only)
- Support of Uplink Synchronisation (TDD only)
Medium Access Control (MAC) – Services

Data transfer (logical channels SAPs)

- Unacknowledged transfer of MAC SDUs between peer MAC entities
- No data segmentation (performed by higher layers) on R.99

Reallocation of radio resources and MAC parameters

- Execution of radio resource reallocation and change of MAC parameters by request of RRC, i.e. change of transport format (combination) sets, change of transport channel type
- Autonomously resource allocation in TDD mode

Reporting of measurements

- Local measurements such as traffic volume and quality indication (reported to RRC)
MAC – Logical Channels

**Logical channels** define *what* information is transported (transport channels (PHY SAP) define *how* data are transported)

- **Control Channels** (transfer of control plane information)
  - Broadcast Control Channel (BCCH) – DL
  - Paging Control Channel (PCCH) – DL
  - Common Control Channel (CCCH) – DL/UL
  - Dedicated Control Channel (DCCH) – DL/UL
  - Shared Channel Control Channel (SHCCH) – DL/UL (TDD)

- **Traffic Channels** (transfer of user plane information)
  - Dedicated Traffic Channel (DTCH) – DL/UL
  - Common Traffic Channel (CTCH) – DL/UL
MAC – Functions (1)

- Mapping between logical channels and transport channels
- Selection of appropriate Transport Format for each Transport Channel depending on instantaneous source rate
- Priority handling (multiplexing) between data flows of one UE (MAC-d)
- Priority handling (scheduling) between different UEs (MAC-c/sh)
- Identification of UEs on common transport channels

Example: DTCH/DCCH mapped on DSCH (TDD only)
**MAC – Functions (2)**

- Multiplexing/demultiplexing of upper layer PDUs on common transport channels
- Multiplexing/demultiplexing of upper layer PDUs on dedicated transport channels
- Traffic volume measurement
- Transport channel type switching (controlled by RRC)
- Ciphering for transparent RLC mode

Example: DTCH/DCCH mapped on DSCH (TDD only)

Example diagram:

- **DTCH** and **DCCH** mapped on common transport channels
- **MAC-d** and **MAC-c/sh** layers in the **PHY** layer
- **AAL2** and **ATM** in the **DschFP** layer
- **AAL2** and **ATM** in the **CRNC** layer
- **MAC-c/sh** and **DschFP** layers in the **Uu** interface
- **Iur** interface with **MAC-d**, **DschFP**, **AAL2**, and **ATM** layers
Logical/ Transport/ Physical Channels Mapping (excerpt, FDD)

Logical Channels
- Control Ch
- Traffic Ch

Transport Channels
- Common Ch (no FPC)
- Common Ch (FPC)
- Dedicated Ch (FPC)

Physical Channels
- P-SCH
- S-SCH
- P-CPICH
- S-CPICH
- P-CCPCH
- PICH
- S-CCPCH
- PRACH
- AICH
- DPDCH
- DPCCH

Key:
- Uplink
- Downlink
- Bidirectional
- Data Transfer
- Association
Radio Link Control (RLC)

- Transparent data transfer (TM)
- Unacknowledged data transfer (UM)
- Acknowledged data transfer (AM)
RLC – Services (1)

**Transparent data transfer (TM)**
- Transmission of upper layer PDUs without adding any protocol information (no RLC header)
- Possibly including segmentation/reassembly functionality

**Unacknowledged data transfer (UM)**
- Transmission of upper layer PDUs without guaranteeing delivery to the peer entity
  - Error detection: The RLC sublayer shall deliver only those SDUs to the receiving upper layer that are free of transmission errors by using the sequence-number check function
  - Immediate delivery: The receiving RLC sublayer entity shall deliver a SDU to the upper layer receiving entity as soon as it arrives at the receiver

**Acknowledged data transfer (AM)**
- Transmission of upper layer PDUs and guaranteed delivery to the peer entity
- Notification of RLC user at transmitting side in case RLC is unable to deliver the data correctly
- in-sequence and out-of-sequence delivery
- error-free delivery (by means of retransmission)
- duplication detection
RLC – Services (2)

Maintenance of QoS as defined by upper layers
• retransmission protocol shall be configurable by layer 3 to provide different levels of QoS

Notification of unrecoverable errors
• RLC notifies the upper layer of errors that cannot be resolved by RLC itself by normal exception handling procedures

There is a single RLC connection per Radio Bearer
## RLC – Functions

- Transfer of user data (AM, UM, TM)
- Segmentation and reassembly (RLC PDU size adapted to transport format)
- Concatenation
- Padding

- Sequence number check (UM mode)
- Duplicate RLC PDUs detection
- In-sequence delivery of upper layer PDUs
- Error correction (selective-repeat ARQ)

- Flow control between RLC peers
- SDU discard
- Protocol error detection and recovery
- Exchange of status information between peer RLC entities
- Ciphering (non-transparent mode)
- Suspend/resume and stop/continue of data transfer
- Re-establishment of AM/UM RLC entity

*Convert variable-size higher layer PDUs into fixed-size RLC PDUs (TBs)*

*Convert radio link errors into packet loss and delay*

*Avoid Tx and Rx buffer overflows or protocol stalling*
Packet Data Convergence Protocol (PDCP)

**Service:** PDCP SDU delivery

PDCP is defined for PS domain only!
PDCP – Functions

Header compression and decompression
- Header compression and decompression of IP data streams (e.g. TCP/IP and RTP/UDP/IP headers)
  
Header compression method is specific to the upper layer protocol combinations, e.g. TCP/IP or RTP/UDP/IP (RFC 2507 & RFC 3095)

Transfer of user data
- PDCP receives PDCP SDU from the NAS and forwards it to the RLC layer and vice versa

Support for lossless SRNS relocation
- Maintenance of PDCP sequence numbers for radio bearers that are configured to support lossless SRNS relocation
**Broadcast/Multicast Control (BMC)**

**Service:**
- broadcast/multicast transmission service in the user plane for common user data in unacknowledged mode

**Functions:**
- Storage of Cell Broadcast Messages
- Traffic volume monitoring and radio resource request for CBS
- Scheduling of BMC messages
- Transmission of BMC messages to UE
- Delivery of Cell Broadcast messages to upper layer (NAS) in the UE
Radio Resource Control (RRC)

Services Provided to Upper Layers

General Control (GC) – information broadcast service
Notification (Nt) – paging and notification broadcast services
Dedicated Control (DC) – connection management and message transfer
RRC – Interaction with Lower Layers

Radio Resource Assignment
[Code, Frequency, TS, TF Set, Mapping, etc.]

Measurement Report

RLC retransmission control

UMTS Networks
Andreas Mitschele-Thiel, Jens Mueckenheim
Nov. 2012
RRC – Functions

RRC handles the control plane signaling of layer 3 between the UEs and UTRAN:
- **Broadcast of information** provided by the non-access stratum (Core Network)
- Broadcast of information related to the access stratum
- Establishment, re-establishment, maintenance and release of **RRC connections**
- Establishment, reconfiguration and release of **Radio Bearers**
- Assignment, reconfiguration and release of radio resources for the RRC connection
- **RRC connection mobility** functions
- **Paging**/notification
- Routing of higher layer PDUs
- Control of requested QoS
- UE **measurement reporting** and control of the reporting
- Outer loop power control
- Control of ciphering
- Slow DCA (TDD)
- Arbitration of radio resources on uplink DCH
- Initial cell selection and re-selection in idle mode
- Integrity protection (message authentication for sensitive data)
- Control of Cell Broadcast Service (CBS)
- **Timing advance control** (TDD)
RRC State Machine

- RRC state machine exists as two peer entities (MS and UTRAN)
- The two peer entities are synchronized (apart from transient situations and error cases)
UTRAN Registration Area (URA)

- URA is known to the UTRAN only
- URA is established in RRC connected mode

URA is independent of RNC area
URA may cover
  - part of an RNC area
  - parts of several RNC areas
URAs may overlap
RRC State Machine

**RRC Idle mode:**
- no connection established between the MS and UTRAN
- no signalling between UTRAN and the MS except for system information sent from UTRAN on a broadcast channel to the MS
- MS can only receive paging messages with a CN identity on the PCH
- no information of the MS is stored in UTRAN
RRC State Machine

RRC Connected mode:
- two main states
  - Cell Connected: MS position is known at the cell level; RRC connection mobility is handled by handover and cell update procedures
  - URA Connected: MS position is known at the URA level; URA updating procedures provide the mobility functionality; no dedicated radio resources are used in the state.
- there is one RNC that is acting as serving RNC, and an RRC connection is established between the MS and this SRNC

An UE has either zero or one RRC connection
RRC State Machine: Details of connected mode

URA_PCH or CELL_PCH state
Neither DCCH nor DTCH are available in these states

CELL_FACH state
DCCH and, if configured, DTCH are available in this state

CELL_DCH state
DCCH and DTCH are available in this state
UMTS RRC State Optimization (PS mode)

Goal: Minimization of Radio Resource Consumption during Idle Times

Tradeoff for idle periods
- retaining in state => continuous state cost or
- move to cheaper state => one time transition cost

Limited resources
- radio resources (transmit power)
- channelization codes
- processing cost (signaling)
- power consumption
- transport resources (Iu, Iub, ...)

Find optimal timeout settings depending on
- traffic model (distribution of idle times)
- cost per state
- cost per transition
- user mobility
- ...
UMTS RRC State Optimization

Optimization of Timeout Values

Timeout Values for States:

1: [Cell_DCH→Cell_PCH] 0.5 sec
2: [Cell_PCH→URA_PCH] 3 sec
3: [URA_PCH→idle] 32 sec

Hinweis: Hier werden relative Zeiten angezeigt, z.B. ist 12 die Zeit, in der ein Wechsel in den Zustand URA_PCH erfolgt werden sollte. In der obigen Tabelle sind absolute Zeiten angegeben, d.h. die Zeit, die vergangen ist, seitdem das letzte Datenträger (Nutzzonen) gesendet wurde.

Einrichtungen:
- [Sperren]
- [Details geheime]

Legende:
- blau: Zustandskosten
- grün: Transitionskosten
- rot: Gesamtkosten

The diagram shows a graph with lines representing the sum, state cost, and transition cost. The graph plots costs against time.