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Technical Specification

LTE;
Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN);
Overall description;
Stage 2
(3GPP TS 36.300 version 8.11.0 Release 8)



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1 Scope

The present document provides an overview and overall description of the E-UTRAN radio interface protocol architecture. Details of the radio interface protocols are specified in companion specifications of the 36 series.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document.*

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications"

[2] 3GPP TR 25.913: "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)"

[3] 3GPP TS 36.201: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; General description".

[4] 3GPP TS 36.211:"Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation "

[5] 3GPP TS 36.212: "Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding"

[6] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"

[7] 3GPP TS 36.214: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements"

[8] IETF RFC 4960 (09/2007): "Stream Control Transmission Protocol"

[9] 3GPP TS 36.302: "Evolved Universal Terrestrial Radio Access (E-UTRA); Services provided by the physical layer"

[11] 3GPP TS 36.304: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode"

[12] 3GPP TS 36.306: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities"

[13] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Acces Control (MAC) protocol specification"

[14] 3GPP TS 36.322: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification"

[15] 3GPP TS 36.323: "Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification"

[16] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC) protocol specification".

[17] 3GPP TS 23.401: "Technical Specification Group Services and System Aspects; GPRS enhancements for E-UTRAN access".

[18] 3GPP TR 24.801: "3GPP System Architecture Evolution (SAE); CT WG1 aspects".

[19] 3GPP TS 23.402: "3GPP System Architecture Evolution: Architecture Enhancements for non-3GPP accesses".

[20] 3GPP TR 24.301: "Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3".

[21] 3GPP TS 36.133: "Evolved Universal Terrestrial Radio Access (E-UTRA); "Requirements for support of radio resource management".

[22] 3GPP TS 33.401: "3GPP System Architecture Evolution: Security Architecture".

[23] 3GPP TS 23.272: "Circuit Switched Fallback in Evolved Packet System; Stage 2".

[24] 3GPP TS 33.401: "3GPP System Architecture Evolution: Security Architecture".

[25] 3GPP TS 36.413: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)".

[26] 3GPP TS 23.003: "Numbering, addressing and identification".

[27] 3GPP TR 25.922: "Radio Resource Management Strategies".

[28] 3GPP TS 23.216: "Single Radio voice Call continuity (SRVCC); Stage 2".

[29] 3GPP TS 32.421: "Subscriber and equipment trace: Trace concepts and requirements".

[30] 3GPP TS 32.422: "Subscriber and equipment trace; Trace control and configuration management".

[31] 3GPP TS 32.423: "Subscriber and equipment trace: Trace data definition and management".

[32] 3GPP TS 22.168: "Earthquake and Tsunami Warning System (ETWS) requirements; Stage 1".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply.

Carrier frequency: center frequency of the cell.

E-RAB: An E-RAB uniquely identifies the concatenation of an S1 Bearer and the corresponding Data Radio Bearer. When an E-RAB exists, there is a one-to-one mapping between this E-RAB and an EPS bearer of the Non Access Stratum as defined in [17].

Frequency layer: set of cells with the same carrier frequency.

Handover: procedure that changes the serving cell of a UE in RRC_CONNECTED.

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

ACK	Acknowledgement
ACLR	Adjacent Channel Leakage Ratio
AM	Acknowledge Mode
AMBR	Aggregate Maximum Bit Rate
ANR	Automatic Neighbour Relation
ARQ	Automatic Repeat Request
AS	Access Stratum

BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BSR	Buffer Status Reports
C/I	Carrier-to-Interference Power Ratio
CAZAC	Constant Amplitude Zero Auto-Correlation
CBC	Cell Broadcast Center
CMC	Connection Mobility Control
CP	Cyclic Prefix
C-plane	Control Plane
C-RNTI	Cell RNTI
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CSG	Closed Subscriber Group
DCCH	Dedicated Control Channel
DL	Downlink
DFTS	DFT Spread OFDM
DRB	Data Radio Bearer
DRX	Discontinuous Reception
DTCH	Dedicated Traffic Channel
DTX	Discontinuous Transmission
DwPTS	Downlink Pilot Time Slot
ECGI	E-UTRAN Cell Global Identifier
ECM	EPS Connection Management
EMM	EPS Mobility Management
eNB	E-UTRAN NodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-RAB	E-UTRAN Radio Access Bearer
ETWS	Earthquake and Tsunami Warning System
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
GERAN	GSM EDGE Radio Access Network
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile communication
GBR	Guaranteed Bit Rate
GP	Guard Period
HARQ	Hybrid ARQ
HO	Handover
HRPD	High Rate Packet Data
HSDPA	High Speed Downlink Packet Access
ICIC	Inter-Cell Interference Coordination
IP	Internet Protocol
LB	Load Balancing
LCR	Low Chip Rate
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MCE	Multi-cell/multicast Coordination Entity
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MIB	Master Information Block
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MSAP	MCH Subframe Allocation Pattern
NACK	Negative Acknowledgement
NAS	Non-Access Stratum
NCC	Next Hop Chaining Counter
NH	Next Hop key
NNSF	NAS Node Selection Function
NR	Neighbour cell Relation

NRT	Neighbour Relation Table
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
P-GW	PDN Gateway
P-RNTI	Paging RNTI
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
PBCH	Physical Broadcast CHannel
PBR	Prioritised Bit Rate
PCCH	Paging Control Channel
PCFICH	Physical Control Format Indicator CHannel
PCH	Paging Channel
PCI	Physical Cell Identifier
PDCCH	Physical Downlink Control CHannel
PDSCH	Physical Downlink Shared CHannel
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHICH	Physical Hybrid ARQ Indicator CHannel
PHY	Physical layer
PLMN	Public Land Mobile Network
PMCH	Physical Multicast CHannel
PRACH	Physical Random Access CHannel
PRB	Physical Resource Block
PSC	Packet Scheduling
PUCCH	Physical Uplink Control CHannel
PUSCH	Physical Uplink Shared CHannel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
RA-RNTI	Random Access RNTI
RAC	Radio Admission Control
RACH	Random Access Channel
RAT	Radio Access Technology
RB	Radio Bearer
RBC	Radio Bearer Control
RBG	Radio Bearer Group
RF	Radio Frequency
RIM	RAN Information Management
RLC	Radio Link Control
RNC	Radio Network Controller
RNL	Radio Network Layer
RNTI	Radio Network Temporary Identifier
ROHC	Robust Header Compression
RRC	Radio Resource Control
RRM	Radio Resource Management
RU	Resource Unit
S-GW	Serving Gateway
S1-MME	S1 for the control plane
SI	System Information
SIB	System Information Block
SI-RNTI	System Information RNTI
S1-U	S1 for the user plane
SAE	System Architecture Evolution
SAP	Service Access Point
SC-FDMA	Single Carrier – Frequency Division Multiple Access
SCH	Synchronization Channel
SDF	Service Data Flow
SDMA	Spatial Division Multiple Access
SDU	Service Data Unit
SeGW	Security Gateway
SFN	System Frame Number
SPID	Subscriber Profile ID for RAT/Frequency Priority

SR	Scheduling Request
SRB	Signalling Radio Bearer
SU	Scheduling Unit
TA	Tracking Area
TB	Transport Block
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TFT	Traffic Flow Template
TM	Transparent Mode
TNL	Transport Network Layer
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UM	Un-acknowledge Mode
UMTS	Universal Mobile Telecommunication System
U-plane	User plane
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
UpPTS	Uplink Pilot Time Slot
VRB	Virtual Resource Block
X2-C	X2-Control plane
X2-U	X2-User plane

4 Overall architecture

The E-UTRAN consists of eNBs, providing the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs / Serving Gateways and eNBs.

The E-UTRAN architecture is illustrated in Figure 4 below.

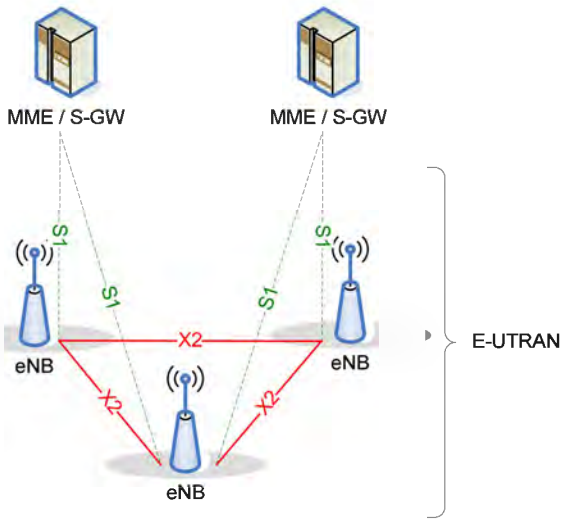


Figure 4-1: Overall Architecture

4.1 Functional Split

The eNB hosts the following functions:

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- Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling);
- IP header compression and encryption of user data stream;
- Selection of an MME at UE attachment when no routing to an MME can be determined from the information provided by the UE;
- Routing of User Plane data towards Serving Gateway;
- Scheduling and transmission of paging messages (originated from the MME);
- Scheduling and transmission of broadcast information (originated from the MME or O&M);
- Measurement and measurement reporting configuration for mobility and scheduling;
- Scheduling and transmission of ETWS messages (originated from the MME).

The MME hosts the following functions (see 3GPP TS 23.401 [17]):

- NAS signalling;
- NAS signalling security;
- AS Security control;
- Inter CN node signalling for mobility between 3GPP access networks;
- Idle mode UE Reachability (including control and execution of paging retransmission);
- Tracking Area list management (for UE in idle and active mode);
- PDN GW and Serving GW selection;
- MME selection for handovers with MME change;
- SGSN selection for handovers to 2G or 3G 3GPP access networks;
- Roaming;
- Authentication;
- Bearer management functions including dedicated bearer establishment;
- Support for ETWS message transmission.

The Serving Gateway (S-GW) hosts the following functions (see 3GPP TS 23.401 [17]):

- The local Mobility Anchor point for inter-eNB handover;
- Mobility anchoring for inter-3GPP mobility;
- E-UTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure;
- Lawful Interception;
- Packet routeing and forwarding;
- Transport level packet marking in the uplink and the downlink;
- Accounting on user and QCI granularity for inter-operator charging;
- UL and DL charging per UE, PDN, and QCI.

The PDN Gateway (P-GW) hosts the following functions (see 3GPP TS 23.401 [17]):

- Per-user based packet filtering (by e.g. deep packet inspection);
- Lawful Interception;

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- UE IP address allocation;
- Transport level packet marking in the downlink;
- UL and DL service level charging, gating and rate enforcement;
- DL rate enforcement based on APN-AMBR;

This is summarized on the figure below where yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

NOTE: it is assumed that no other logical E-UTRAN node than the eNB is needed for RRM purposes. Moreover, due to the different usage of inter-cell RRM functionalities, each inter-cell RRM functionality should be considered separately in order to assess whether it should be handled in a centralised manner or in a distributed manner.

NOTE: MBMS related functions in E-UTRAN are described separately in subclause 15.

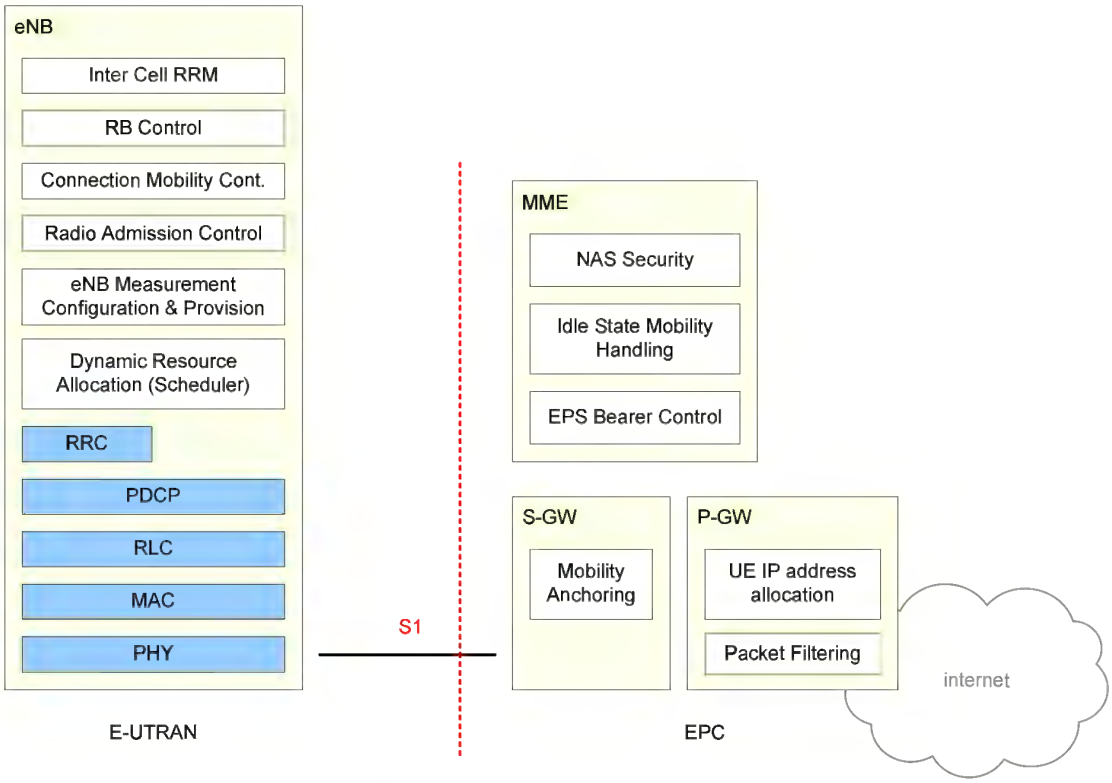


Figure 4.1-1: Functional Split between E-UTRAN and EPC

4.2 Interfaces

4.2.1 S1 Interface

4.2.2 X2 Interface

4.3 Radio Protocol architecture

In this subclause, the radio protocol architecture of E-UTRAN is given for the user plane and the control plane.

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4.3.1 User plane

The figure below shows the protocol stack for the user-plane, where PDCP, RLC and MAC sublayers (terminated in eNB on the network side) perform the functions listed for the user plane in subclause 6, e.g. header compression, ciphering, scheduling, ARQ and HARQ;

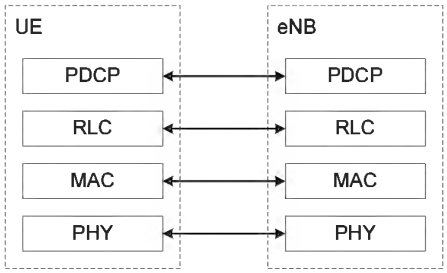


Figure 4.3.1-1: User-plane protocol stack

4.3.2 Control plane

The figure below shows the protocol stack for the control-plane, where:

- PDCP sublayer (terminated in eNB on the network side) performs the functions listed for the control plane in subclause 6, e.g. ciphering and integrity protection;
- RLC and MAC sublayers (terminated in eNB on the network side) perform the same functions as for the user plane;
- RRC (terminated in eNB on the network side) performs the functions listed in subclause 7, e.g.:
  - Broadcast;
  - Paging;
  - RRC connection management;
  - RB control;
  - Mobility functions;
  - UE measurement reporting and control.
- NAS control protocol (terminated in MME on the network side) performs among other things:
  - EPS bearer management;
  - Authentication;
  - ECM-IDLE mobility handling;
  - Paging origination in ECM-IDLE;
  - Security control.

NOTE: the NAS control protocol is not covered by the scope of this TS and is only mentioned for information.

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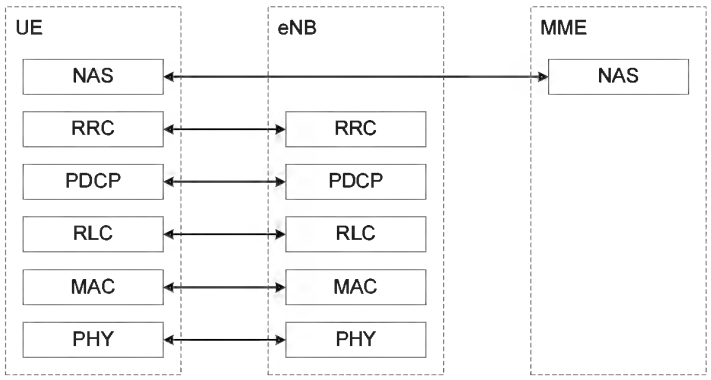


Figure 4.3.2-1: Control-plane protocol stack

4.4 Synchronization

Diverse methods and techniques are preferred depending on synchronization requirements. As no single method can cover all E-UTRAN applications a logical port at eNB may be used for reception of timing and/or frequency and/or phase inputs pending to the synchronization method chosen.

4.5 IP fragmentation

Fragmentation function in IP layer on S1 and X2 shall be supported.

Configuration of S1-U (X2-U) link MTU in the eNB/ S-GW according to the MTU of the network domain the node belongs to shall be considered as a choice at network deployment. The network may employ various methods to handle IP fragmentation, but the specific methods to use are implementation dependant.

At the establishment/modification of an EPS bearer, the network may signal a value that is to be used as MTU by the UE IP stack (it is FFS how the requirement on the UE should be formulated). It is also FFS if the MTU is signalled by the MME or the eNB.

4.6 Support of HeNBs

4.6.1 Architecture

Figure 4.6.1-1 shows a logical architecture for the HeNB that has a set of S1 interfaces to connect the HeNB to the EPC.

The configuration and authentication entities as shown here should be common to HeNBs and HNBs.

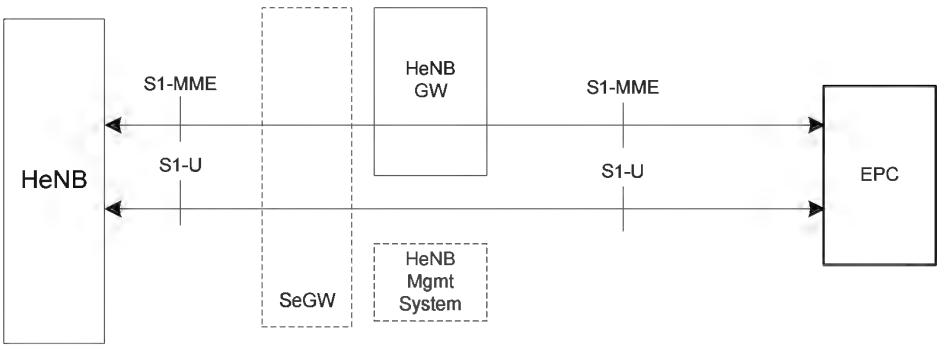


Figure 4.6.1-1: E-UTRAN HeNB Logical Architecture

The E-UTRAN architecture may deploy a Home eNB Gateway (HeNB GW) to allow the S1 interface between the HeNB and the EPC to scale to support a large number of HeNBs. The HeNB GW serves as a concentrator for the C-Plane, specifically the S1-MME interface. The S1-U interface from the HeNB may be terminated at the HeNB GW, or a direct logical U-Plane connection between HeNB and S-GW may be used (as shown in Figure 4.6.1-1).

This version of the specification does not support X2 connectivity of HeNBs.

The S1 interface is defined as the interface:

- Between the HeNB GW and the Core Network,
- Between the HeNB and the HeNB GW,
- Between the HeNB and the Core Network,
- Between the eNB and the Core Network.

The HeNB GW appears to the MME as an eNB. The HeNB GW appears to the HeNB as an MME. The S1 interface between the HeNB and the EPC is the same whether the HeNB is connected to the EPC via a HeNB GW or not.

The HeNB GW shall connect to the EPC in a way that inbound and outbound mobility to cells served by the HeNB GW shall not necessarily require inter MME handovers. One HeNB serves only one cell.

The functions supported by the HeNB shall be the same as those supported by an eNB (with the possible exception of NNSF) and the procedures run between a HeNB and the EPC shall be the same as those between an eNB and the EPC.

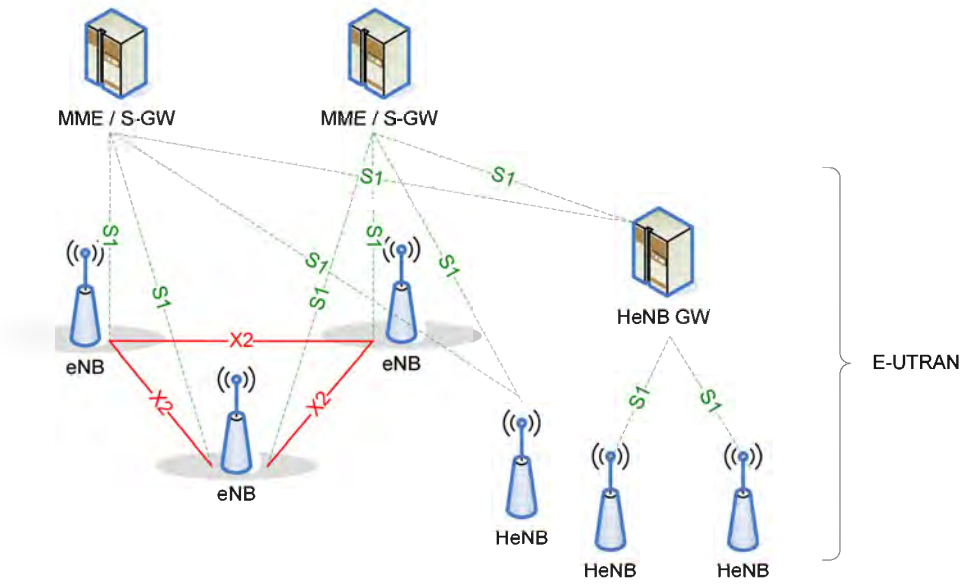


Figure 4.6.1-2: Overall E-UTRAN Architecture with deployed HeNB GW.

4.6.2 Functional Split

The HeNB hosts the same functions as an eNB as described in section 4.1, with the following additional specifications in case of connection to the HeNB GW:

- Discovery of a suitable Serving HeNB GW
- A HeNB shall only connect to a single HeNB GW at one time, namely no S1 Flex function shall be used at the HeNB in case of connection to the HeNB GW.
  - If the HeNB is connected to a HeNB GW, it will not simultaneously connect to another HeNB GW, or another MME.

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- The TAC and PLMN ID used by the HeNB shall also be supported by the HeNB GW.
- When the HeNB connects to a HeNB GW, selection of an MME at UE attachment is hosted by the HeNB GW instead of the HeNB;
- HeNBs may be deployed without network planning. A HeNB may be moved from one geographical area to another and therefore it may need to connect to different HeNB GWs depending on its location.

The HeNB GW hosts the following functions:

- Relaying UE-associated S1 application part messages between the MME serving the UE and the HeNB serving the UE;
- Terminating non-UE associated S1 application part procedures towards the HeNB and towards the MME. Note that when a HeNB GW is deployed, non-UE associated procedures shall be run between HeNBs and the HeNB GW and between the HeNB GW and the MME.
- Optionally terminating S1-U interface with the HeNB and with the S-GW.
- Supporting TAC and PLMN ID used by the HeNB.
- X2 interfaces shall not be established between the HeNB GW and other nodes.
- Optionally performing paging optimisation in case the Allowed CSG List of the paged UE is included in the PAGING message.

In addition to functions specified in section 4.1, the MME hosts the following functions:

- Access control for UEs that are members of Closed Subscriber Groups (CSG).
- Optionally performing paging optimisation.

NOTE: The MME or HeNB GW should not include the Allowed CSG List when sending the paging message directly to an untrusted HeNB or eNB.

4.6.3 Interfaces

4.6.3.1 Protocol Stack for S1 User Plane

The S1-U data plane is defined between the HeNB, HeNB GW and the S-GW. The figures below shows the S1-U protocol stack with and without the HeNB GW.

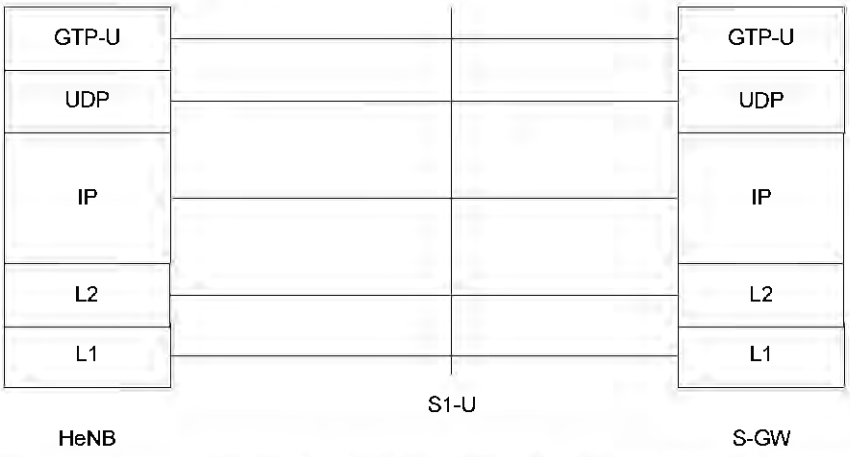


Figure 4.6.3.1-1: User plane for S1-U interface for HeNB without HeNB GW

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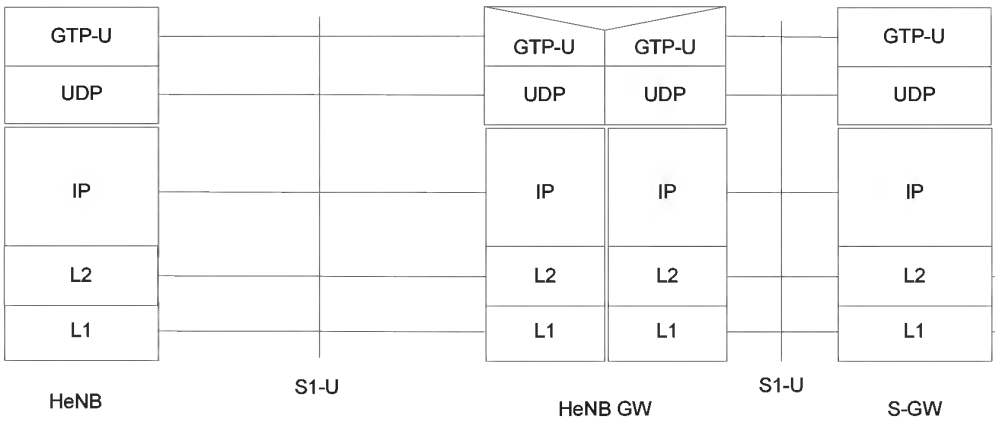


Figure 4.6.3.1-2: User plane for S1-U interface for HeNB with HeNB GW

The HeNB GW may optionally terminate the user plane towards the HeNB and towards the S-GW, and provide a relay function for relaying User Plane data between the HeNB and the S-GW.

4.6.3.2 Protocol Stacks for S1 Control Plane

The two figures below show the S1-MME protocol stacks with and without the HeNB GW.

When the HeNB GW is not present (Fig. 4.6.3.2-1), all the S1 procedures are terminated at the HeNB and the MME.

When present (Fig. 4.6.3.2-2), the HeNB GW shall terminate the non-UE-dedicated procedures – both with the HeNB, and with the MME. The HeNB GW shall provide a relay function for relaying Control Plane data between the HeNB and the MME. The scope of any protocol function associated to a non-UE-dedicated procedure shall be between HeNB and HeNB GW and/or between HeNB GW and MME.

Any protocol function associated to an UE-dedicated-procedure shall reside within the HeNB and the MME only.

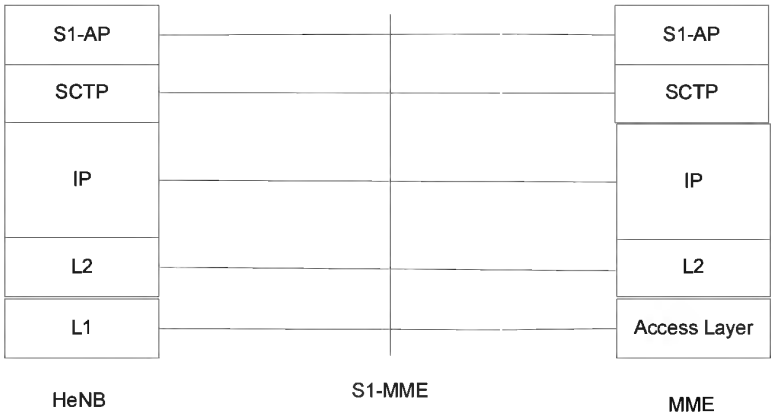


Figure 4.6.3.2-1: Control plane for S1-MME Interface for HeNB to MME without the HeNB GW

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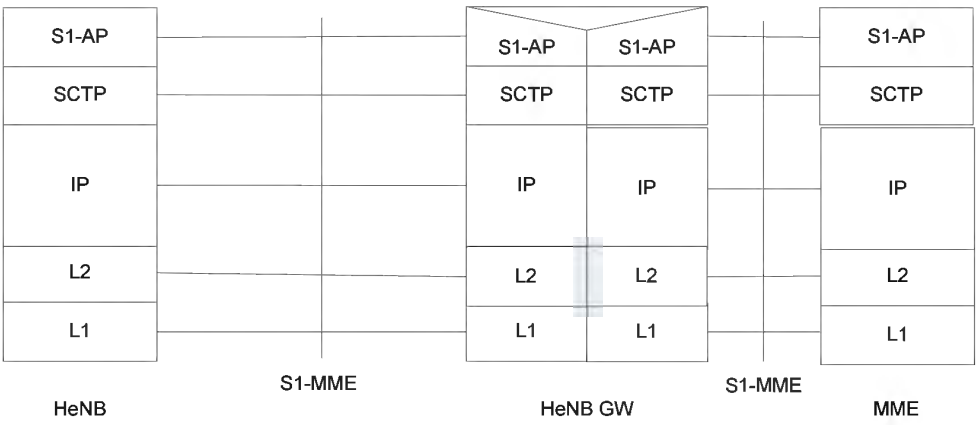


Figure 4.6.3.2-2: Control plane for S1-MME Interface for HeNB to MME with the HeNB GW

5 Physical Layer for E-UTRA

Downlink and uplink transmissions are organized into radio frames with 10 ms duration. Two radio frame structures are supported:

- Type 1, applicable to FDD,
- Type 2, applicable to TDD.

Frame structure Type 1 is illustrated in Figure 5.1-1. Each 10 ms radio frame is divided into ten equally sized sub-frames. Each sub-frame consists of two equally sized slots. For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain.

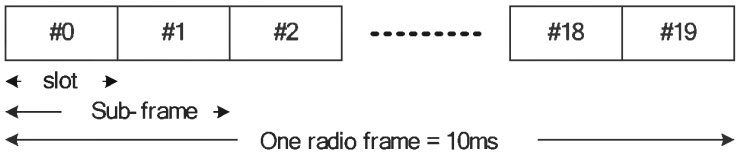


Figure 5.1-1: Frame structure type 1

Frame structure Type 2 is illustrated in Figure 5.1-2. Each 10 ms radio frame consists of two half-frames of 5 ms each. Each half-frame consists of eight slots of length 0.5 ms and three special fields: DwPTS, GP and UpPTS. The length of DwPTS and UpPTS is configurable subject to the total length of DwPTS, GP and UpPTS being equal to 1ms. Both 5ms and 10ms switch-point periodicity are supported. Subframe 1 in all configurations and subframe 6 in configuration with 5ms switch-point periodicity consist of DwPTS, GP and UpPTS. Subframe 6 in configuration with 10ms switch-point periodicity consists of DwPTS only. All other subframes consist of two equally sized slots.

For TDD, GP is reserved for downlink to uplink transition. Other Subframes/Fields are assigned for either downlink or uplink transmission. Uplink and downlink transmissions are separated in the time domain.

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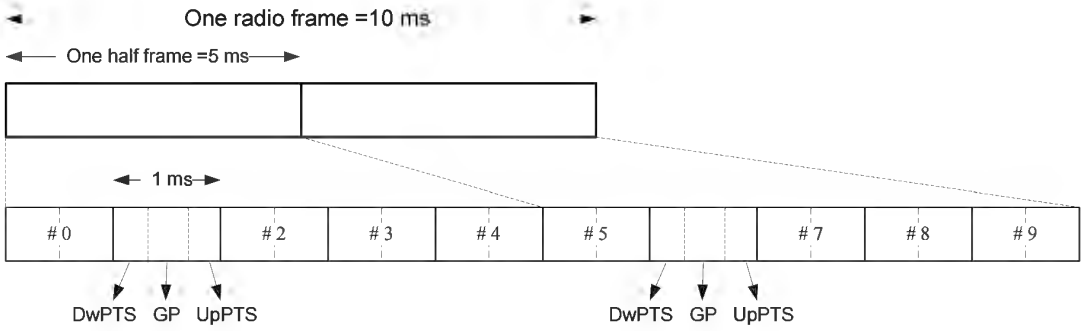


Figure 5.1-2: Frame structure type 2 (for 5ms switch-point periodicity)

Table 5.1-1: Uplink-downlink allocations.

Configuration	Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

The physical channels of E-UTRA are:

Physical broadcast channel (PBCH)

- The coded BCH transport block is mapped to four subframes within a 40 ms interval;
- 40 ms timing is blindly detected, i.e. there is no explicit signalling indicating 40 ms timing;
- Each subframe is assumed to be self-decodable, i.e. the BCH can be decoded from a single reception, assuming sufficiently good channel conditions.

Physical control format indicator channel (PCFICH)

- Informs the UE about the number of OFDM symbols used for the PDCCHs;
- Transmitted in every downlink or special subframe.

Physical downlink control channel (PDCCH)

- Informs the UE about the resource allocation of PCH and DL-SCH, and Hybrid ARQ information related to DL-SCH;
- Carries the uplink scheduling grant.

Physical Hybrid ARQ Indicator Channel (PHICH)

- Carries Hybrid ARQ ACK/NAKs in response to uplink transmissions.

Physical downlink shared channel (PDSCH)

- Carries the DL-SCH and PCH.

Physical multicast channel (PMCH)

- Carries the MCH.

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Physical uplink control channel (PUCCH)

- Carries Hybrid ARQ ACK/NAKs in response to downlink transmission;
- Carries Scheduling Request (SR);
- Carries CQI reports.

Physical uplink shared channel (PUSCH)

- Carries the UL-SCH.

Physical random access channel (PRACH)

- Carries the random access preamble.

5.1 Downlink Transmission Scheme

5.1.1 Basic transmission scheme based on OFDM

The downlink transmission scheme is based on conventional OFDM using a cyclic prefix. The OFDM sub-carrier spacing is $\Delta f = 15$ kHz. 12 consecutive sub-carriers during one slot correspond to one downlink *resource block*. In the frequency domain, the number of resource blocks, N_{RB}, can range from $N_{RB\text{-}min} = 6$ to $N_{RB\text{-}max} = 110$.

In addition there is also a reduced sub-carrier spacing $\Delta f_{low} = 7.5$ kHz, only for MBMS-dedicated cell.

In the case of 15 kHz sub-carrier spacing there are two cyclic-prefix lengths, corresponding to seven and six OFDM symbols per slot respectively.

- Normal cyclic prefix: $T_{CP} = 160 \times Ts$ (OFDM symbol #0) , $T_{CP} = 144 \times Ts$ (OFDM symbol #1 to #6)
- Extended cyclic prefix: $T_{CP\text{-}e} = 512 \times Ts$ (OFDM symbol #0 to OFDM symbol #5)

  where $T_s = 1/(2048 \times \Delta f)$

In case of 7.5 kHz sub-carrier spacing, there is only a single cyclic prefix length $T_{CP\text{-}low} = 1024 \times Ts$, corresponding to 3 OFDM symbols per slot.

In case of FDD, operation with half duplex from UE point of view is supported.

5.1.2 Physical-layer processing

The downlink physical-layer processing of transport channels consists of the following steps:

- CRC insertion: 24 bit CRC is the baseline for PDSCH;
- Channel coding: Turbo coding based on QPP inner interleaving with trellis termination;
- Physical-layer hybrid-ARQ processing;
- Channel interleaving;
- Scrambling: transport-channel specific scrambling on DL-SCH, BCH, and PCH. Common MCH scrambling for all cells involved in a specific MBSFN transmission;
- Modulation: QPSK, 16QAM, and 64QAM;
- Layer mapping and pre-coding;
- Mapping to assigned resources and antenna ports.

5.1.3 Physical downlink control channel

The downlink control signalling (PDCCH) is located in the first n OFDM symbols where $n \leq 4$ and consists of:

- Transport format and resource allocation related to DL-SCH and PCH, and hybrid ARQ information related to DL-SCH;
- Transport format, resource allocation, and hybrid-ARQ information related to UL-SCH;

Transmission of control signalling from these groups is mutually independent.

Multiple physical downlink control channels are supported and a UE monitors a set of control channels.

Control channels are formed by aggregation of control channel elements, each control channel element consisting of a set of resource elements. Different code rates for the control channels are realized by aggregating different numbers of control channel elements.

QPSK modulation is used for all control channels.

Each separate control channel has its own set of x-RNTI.

There is an implicit relation between the uplink resources used for dynamically scheduled data transmission, or the DL control channel used for assignment, and the downlink ACK/NAK resource used for feedback

5.1.4 Downlink Reference signal

The downlink reference signals consist of known reference symbols inserted in the first and third last OFDM symbol of each slot. There is one reference signal transmitted per downlink antenna port. The number of downlink antenna ports equals 1, 2, or 4. The two-dimensional reference signal sequence is generated as the symbol-by-symbol product of a two-dimensional orthogonal sequence and a two-dimensional pseudo-random sequence. There are 3 different two-dimensional orthogonal sequences and 170 different two-dimensional pseudo-random sequences. Each cell identity corresponds to a unique combination of one orthogonal sequence and one pseudo-random sequence, thus allowing for 504 unique cell identities 168 cell identity groups with 3 cell identities in each group).

Frequency hopping can be applied to the downlink reference signals. The frequency hopping pattern has a period of one frame (10 ms). Each frequency hopping pattern corresponds to one cell identity group.

The downlink MBSFN reference signals consist of known reference symbols inserted every other sub-carrier in the 3rd, 7th and 11th OFDM symbol of sub-frame in case of 15kHz sub-carrier spacing and extended cyclic prefix

5.1.5 Downlink multi-antenna transmission

Multi-antenna transmission with 2 and 4 transmit antennas is supported. The maximum number of codeword is two irrespective to the number of antennas with fixed mapping between code words to layers.

Spatial division multiplexing (SDM) of multiple modulation symbol streams to a single UE using the same time-frequency (-code) resource, also referred to as Single-User MIMO (SU-MIMO) is supported. When a MIMO channel is solely assigned to a single UE, it is known as SU-MIMO. Spatial division multiplexing of modulation symbol streams to different UEs using the same time-frequency resource, also referred to as MU-MIMO, is also supported. There is semi-static switching between SU-MIMO and MU-MIMO per UE.

In addition, the following techniques are supported:

- Code-book-based pre-coding with a single pre-coding feedback per full system bandwidth when the system bandwidth (or subset of resource blocks) is smaller or equal to12RB and per 5 adjacent resource blocks or the full system bandwidth (or subset of resource blocks) when the system bandwidth is larger than 12RB.
- Rank adaptation with single rank feedback referring to full system bandwidth. Node B can override rank report.

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5.1.6 MBSFN transmission

MBSFN is supported for the MCH transport channel. Multiplexing of transport channels using MBSFN and non-MBSFN transmission is done on a per-sub-frame basis. Additional reference symbols, transmitted using MBSFN are transmitted within MBSFN subframes.

5.1.7 Physical layer procedure

5.1.7.1 Link adaptation

Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the shared data channel. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a single stream.

5.1.7.2 Power Control

Downlink power control can be used.

5.1.7.3 Cell search

Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the Cell ID of that cell. E-UTRA cell search supports a scalable overall transmission bandwidth corresponding to 72 sub-carriers and upwards.

E-UTRA cell search is based on following signals transmitted in the downlink: the primary and secondary synchronization signals, the downlink reference signals.

The primary and secondary synchronization signals are transmitted over the centre 72 sub-carriers in the first and sixth subframe of each frame.

Neighbour-cell search is based on the same downlink signals as initial cell search.

5.1.8 Physical layer measurements definition

The physical layer measurements to support mobility are classified as:

- within E-UTRAN (intra-frequency, inter-frequency);
- between E-UTRAN and GERAN/UTRAN (inter-RAT);
- between E-UTRAN and non-3GPP RAT (Inter 3GPP access system mobility).

For measurements within E-UTRAN at least two basic UE measurement quantities shall be supported:

- Reference symbol received power (RSRP);
- E-UTRA carrier received signal strength indicator (RSSI).

5.2 Uplink Transmission Scheme

5.2.1 Basic transmission scheme

For both FDD and TDD, the uplink transmission scheme is based on single-carrier FDMA, more specifically DFTS-OFDM.

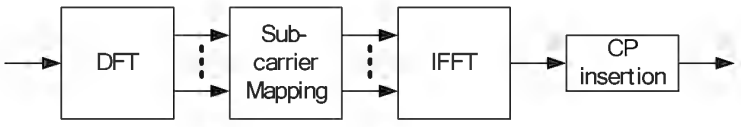


Figure 5.2.1-1: Transmitter scheme of SC-FDMA

The uplink sub-carrier spacing $\Delta f = 15$ kHz. The sub-carriers are grouped into sets of 12 consecutive sub-carriers, corresponding to the uplink resource blocks. 12 consecutive sub-carriers during one slot correspond to one uplink *resource block*. In the frequency domain, the number of resource blocks, N_{RB}, can range from $N_{RB\text{-}min} = 6$ to $N_{RB\text{-}max} = 110$.

There are two cyclic-prefix lengths defined: Normal cyclic prefix and extended cyclic prefix corresponding to seven and six SC-FDMA symbol per slot respectively.

- Normal cyclic prefix: $T_{CP} = 160 \times Ts$ (SC-FDMA symbol #0) , $T_{CP} = 144 \times Ts$ (SC-FDMA symbol #1 to #6)
- Extended cyclic prefix: $T_{CP\text{-}e} = 512 \times Ts$ (SC-FDMA symbol #0 to SC-FDMA symbol #5)

5.2.2 Physical-layer processing

The uplink physical layer processing of transport channels consists of the following steps:

- CRC insertion: 24 bit CRC is the baseline for PUSCH;
- Channel coding: turbo coding based on QPP inner interleaving with trellis termination;
- Physical-layer hybrid-ARQ processing;
- Scrambling: UE-specific scrambling;
- Modulation: QPSK, 16QAM, and 64QAM (64 QAM optional in UE);
- Mapping to assigned resources and antennas ports.

5.2.3 Physical uplink control channel

The PUCCH shall be mapped to a control channel resource in the uplink. A control channel resource is defined by a code and two resource blocks, consecutive in time, with hopping at the slot boundary.

Depending on presence or absence of uplink timing synchronization, the uplink physical control signalling can differ.

In the case of time synchronization being present, the outband control signalling consists of:

- CQI;
- ACK/NAK;
- Scheduling Request (SR).

The CQI informs the scheduler about the current channel conditions as seen by the UE. If MIMO transmission is used, the CQI includes necessary MIMO-related feedback.

The HARQ feedback in response to downlink data transmission consists of a single ACK/NAK bit per HARQ process.

PUCCH resources for SR and CQI reporting are assigned and can be revoked through RRC signalling. An SR is not necessarily assigned to UEs acquiring synchronization through the RACH (i.e. synchronised UEs may or may not have a dedicated SR channel). PUCCH resources for SR and CQI are lost when the UE is no longer synchronized.

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5.2.4 Uplink Reference signal

Uplink reference signals [for channel estimation for coherent demodulation] are transmitted in the 4-th block of the slot [*assumed normal CP*]. The uplink reference signals sequence length equals the size (number of sub-carriers) of the assigned resource.

The uplink reference signals are based on prime-length Zadoff-chu sequences that are cyclically extended to the desired length.

Multiple reference signals can be created:

- Based on different Zadoff-Chu sequence from the same set of Zadoff-Chu sequences;
- Different shifts of the same sequence.

5.2.5 Random access preamble

The physical layer random access burst consists of a cyclic prefix, a preamble, and a guard time during which nothing is transmitted.

The random access preambles are generated from Zadoff-Chu sequences with zero correlation zone, ZC-ZCZ, generated from one or several root Zadoff-Chu sequences.

5.2.6 Uplink multi-antenna transmission

The baseline antenna configuration for uplink MIMO is MU-MIMO. To allow for MU-MIMO reception at the Node B, allocation of the same time and frequency resource to several UEs, each of which transmitting on a single antenna, is supported.

Closed loop type adaptive antenna selection transmit diversity shall be supported for FDD (optional in UE).

5.2.7 Physical channel procedure

5.2.7.1 Link adaptation

Uplink link adaptation is used in order to guarantee the required minimum transmission performance of each UE such as the user data rate, packet error rate, and latency, while maximizing the system throughput.

Three types of link adaptation are performed according to the channel conditions, the UE capability such as the maximum transmission power and maximum transmission bandwidth etc., and the required QoS such as the data rate, latency, and packet error rate etc. Three link adaptation methods are as follows.

- Adaptive transmission bandwidth;
- Transmission power control;
- Adaptive modulation and channel coding rate.

5.2.7.2 Uplink Power control

Intra-cell power control: the power spectral density of the uplink transmissions can be influenced by the eNB.

5.2.7.3 Uplink timing control

The timing advance is derived from the UL received timing and sent by the eNB to the UE which the UE uses to advance/delay its timings of transmissions to the eNB so as to compensate for propagation delay and thus time align the transmissions from different UEs with the receiver window of the eNB.

The timing advance command is on a per need basis with a granularity in the step size of 0.52 μs ($16 \times T_s$).

5.3 Transport Channels

The physical layer offers information transfer services to MAC and higher layers. The physical layer transport services are described by *how* and with what characteristics data are transferred over the radio interface. An adequate term for this is 'Transport Channel'.

NOTE: This should be clearly separated from the classification of *what* is transported, which relates to the concept of logical channels at MAC sublayer.

Downlink transport channel types are:

1. **Broadcast Channel (BCH)** characterised by:
   - fixed, pre-defined transport format;
   - requirement to be broadcast in the entire coverage area of the cell.
2. **Downlink Shared Channel (DL-SCH)** characterised by:
   - support for HARQ;
   - support for dynamic link adaptation by varying the modulation, coding and transmit power;
   - possibility to be broadcast in the entire cell;
   - possibility to use beamforming;
   - support for both dynamic and semi-static resource allocation;
   - support for UE discontinuous reception (DRX) to enable UE power saving.

NOTE: the possibility to use slow power control depends on the physical layer.

3. **Paging Channel (PCH)** characterised by:
   - support for UE discontinuous reception (DRX) to enable UE power saving (DRX cycle is indicated by the network to the UE);
   - requirement to be broadcast in the entire coverage area of the cell;
   - mapped to physical resources which can be used dynamically also for traffic/other control channels.
4. **Multicast Channel (MCH)** characterised by:
   - requirement to be broadcast in the entire coverage area of the cell;
   - support for MBSFN combining of MBMS transmission on multiple cells;
   - support for semi-static resource allocation e.g. with a time frame of a long cyclic prefix.

Uplink transport channel types are:

1. **Uplink Shared Channel (UL-SCH)** characterised by:
   - possibility to use beamforming; (likely no impact on specifications)
   - support for dynamic link adaptation by varying the transmit power and potentially modulation and coding;
   - support for HARQ;
   - support for both dynamic and semi-static resource allocation.

NOTE: the possibility to use uplink synchronisation and timing advance depend on the physical layer.

2. **Random Access Channel(s) (RACH)** characterised by:
   - limited control information;

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- collision risk;

NOTE: the possibility to use open loop power control depends on the physical layer solution.

5.3.1 Mapping between transport channels and physical channels

The figures below depict the mapping between transport and physical channels:

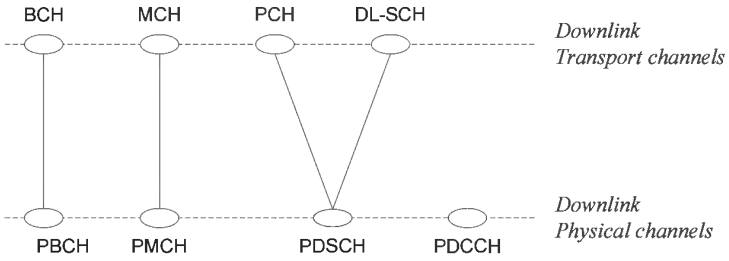


Figure 5.3.1-1: Mapping between downlink transport channels and downlink physical channels

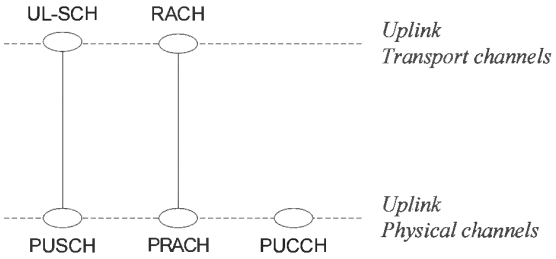


Figure 5.3.1-2: Mapping between uplink transport channels and uplink physical channels

5.4 E-UTRA physical layer model

The E-UTRAN physical layer model is captured in TS 36.302 [9].

5.4.1 Void

5.4.2 Void

6 Layer 2

Layer 2 is split into the following sublayers: Medium Access Control (MAC), Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP).

This subclause gives a high level description of the Layer 2 sub-layers in terms of services and functions. The two figures below depict the PDCP/RLC/MAC architecture for downlink and uplink, where:

- Service Access Points (SAP) for peer-to-peer communication are marked with circles at the interface between sublayers. The SAP between the physical layer and the MAC sublayer provides the transport channels. The SAPs between the MAC sublayer and the RLC sublayer provide the logical channels.

- The multiplexing of several logical channels (i.e. radio bearers) on the same transport channel (i.e. transport block) is performed by the MAC sublayer;
- In both uplink and downlink, only one transport block is generated per TTI in the non-MIMO case.

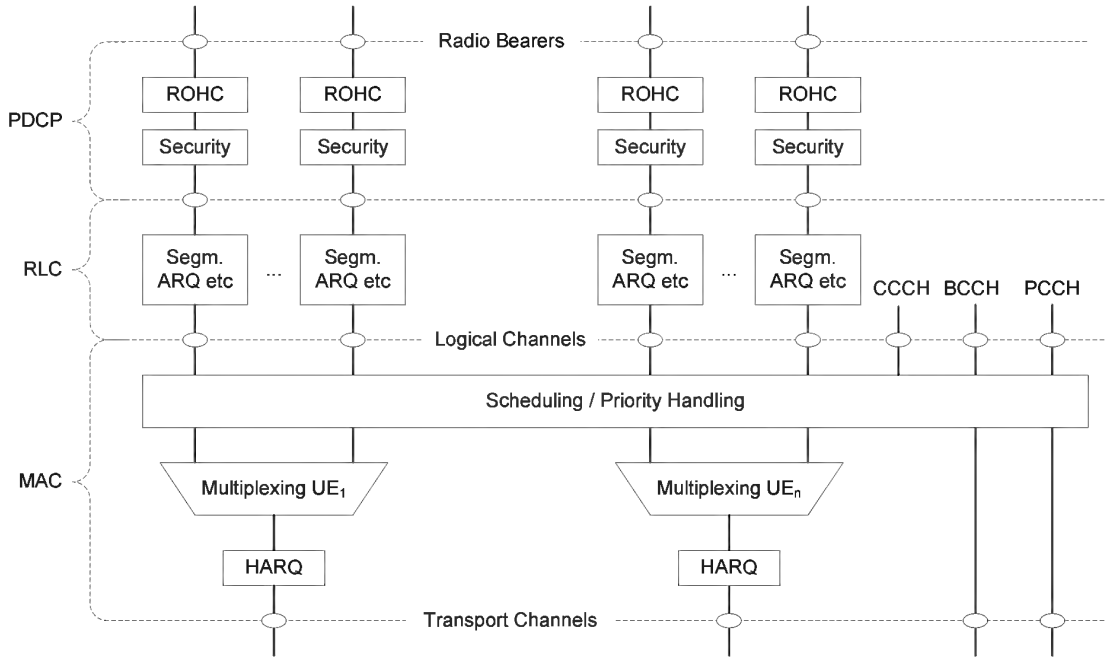


Figure 6-1: Layer 2 Structure for DL

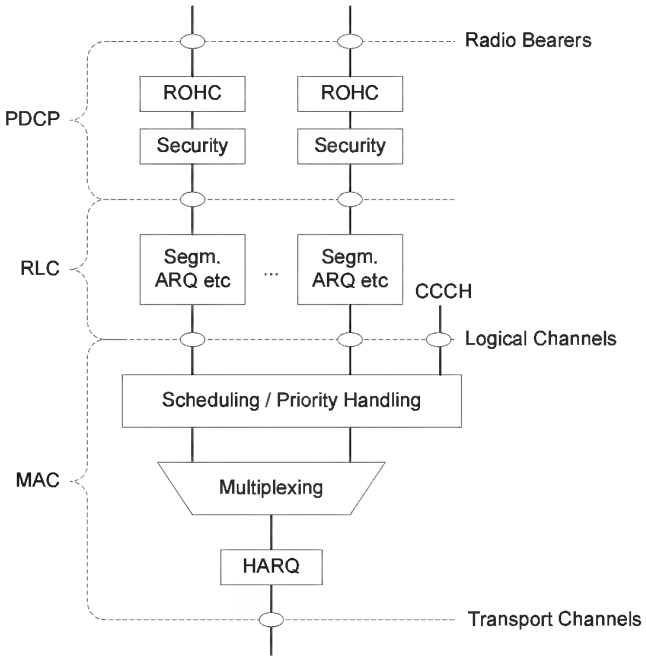


Figure 6-2: Layer 2 Structure for UL

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NOTE: The eNB may not be able to guarantee that a L2 buffer overflow will never occur. If such overflow occurs, UE may discard packets in the L2 buffer.

6.1 MAC Sublayer

This subclause provides an overview on services and functions provided by the MAC sublayer.

6.1.1 Services and Functions

The main services and functions of the MAC sublayer include:

- Mapping between logical channels and transport channels;
- Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels;
- scheduling information reporting;
- Error correction through HARQ;
- Priority handling between logical channels of one UE;
- Priority handling between UEs by means of dynamic scheduling;
- Transport format selection;
- Padding.

6.1.2 Logical Channels

Different kinds of data transfer services as offered by MAC. Each logical channel type is defined by what type of information is transferred.

A general classification of logical channels is into two groups:

- Control Channels (for the transfer of control plane information);
- Traffic Channels (for the transfer of user plane information).

There is one MAC entity per cell. MAC generally consists of several function blocks (transmission scheduling functions, per UE functions, MAC control functions, transport block generation…). Transparent Mode is only applied to BCCH and PCCH.

6.1.2.1 Control Channels

Control channels are used for transfer of control plane information only. The control channels offered by MAC are:

- **Broadcast Control Channel (BCCH)**

  A downlink channel for broadcasting system control information.

- **Paging Control Channel (PCCH)**

  A downlink channel that transfers paging information and system information change notifications. This channel is used for paging when the network does not know the location cell of the UE.

- **Common Control Channel (CCCH)**

  Channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network.

- **Dedicated Control Channel (DCCH)**

A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.

6.1.2.2 Traffic Channels

Traffic channels are used for the transfer of user plane information only. The traffic channels offered by MAC are:

- **Dedicated Traffic Channel (DTCH)**

  A Dedicated Traffic Channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

6.1.3 Mapping between logical channels and transport channels

6.1.3.1 Mapping in Uplink

The figure below depicts the mapping between uplink logical channels and uplink transport channels:

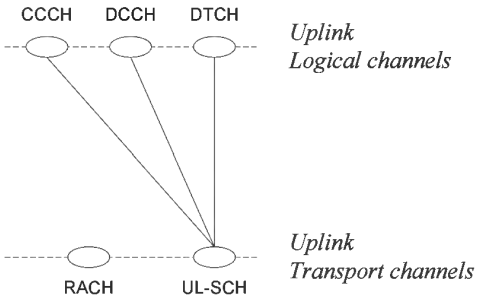


Figure 6.1.3.1-1: Mapping between uplink logical channels and uplink transport channels

In Uplink, the following connections between logical channels and transport channels exist:

- CCCH can be mapped to UL-SCH;
- DCCH can be mapped to UL- SCH;
- DTCH can be mapped to UL-SCH.

6.1.3.2 Mapping in Downlink

The figure below depicts the mapping between downlink logical channels and downlink transport channels:

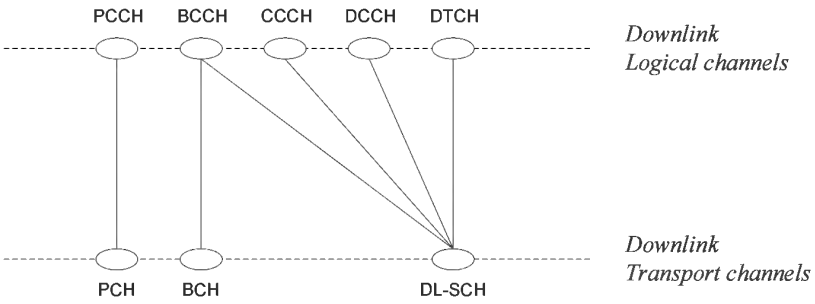


Figure 6.1.3.2-1: Mapping between downlink logical channels and downlink transport channels

In Downlink, the following connections between logical channels and transport channels exist:

- BCCH can be mapped to BCH;
- BCCH can be mapped to DL-SCH;
- PCCH can be mapped to PCH;
- CCCH can be mapped to DL-SCH;
- DCCH can be mapped to DL-SCH;
- DTCH can be mapped to DL-SCH.

6.2 RLC Sublayer

This subclause provides an overview on services, functions and PDU structure provided by the RLC sublayer. Note that:

- The reliability of RLC is configurable: some radio bearers may tolerate rare losses (e.g. TCP traffic);
- Radio Bearers are not characterized by a fixed sized data unit (e.g. a fixed sized RLC PDU).

6.2.1 Services and Functions

The main services and functions of the RLC sublayer include:

- Transfer of upper layer PDUs;
- Error Correction through ARQ (only for AM data transfer);
- Concatenation, segmentation and reassembly of RLC SDUs (only for UM and AM data transfer);
- Re-segmentation of RLC data PDUs (only for AM data transfer);
- In sequence delivery of upper layer PDUs (only for UM and AM data transfer);
- Duplicate detection (only for UM and AM data transfer);
- Protocol error detection and recovery;
- RLC SDU discard (only for UM and AM data transfer);
- RLC re-establishment.

6.2.2 PDU Structure

Figure 6.2.2-1 below depicts the RLC PDU structure where:

- The PDU sequence number carried by the RLC header is independent of the SDU sequence number (i.e. PDCP sequence number);
- A red dotted line indicates the occurrence of segmentation;
- Because segmentation only occurs when needed and concatenation is done in sequence, the content of an RLC PDU can generally be described by the following relations:
  - {0; 1} last segment of SDU_i + [0; n] complete SDUs + {0; 1} first segment of SDU_{i+n+1} ; or
  - 1 segment of SDU_i .

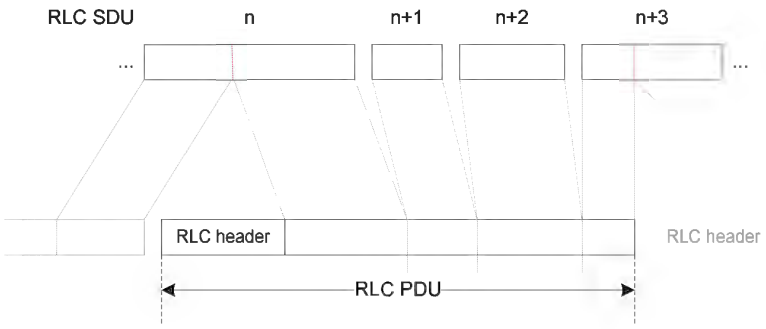


Figure 6.2.2-1: RLC PDU Structure

6.3 PDCP Sublayer

This subclause provides an overview on services, functions and PDU structure provided by the PDCP sublayer.

6.3.1 Services and Functions

The main services and functions of the PDCP sublayer for the user plane include:

- Header compression and decompression: ROHC only;
- Transfer of user data;
- In-sequence delivery of upper layer PDUs at PDCP re-establishment procedure for RLC AM;
- Duplicate detection of lower layer SDUs at PDCP re-establishment procedure for RLC AM;
- Retransmission of PDCP SDUs at handover for RLC AM;
- Ciphering and deciphering;
- Timer-based SDU discard in uplink.

NOTE: When compared to UTRAN, the *lossless DL RLC PDU size change* is not required.

The main services and functions of the PDCP for the control plane include:

- Ciphering and Integrity Protection;
- Transfer of control plane data.

6.3.2 PDU Structure

Figure 6.3.2-1 below depicts the PDCP PDU structure for user plane data, where:

- PDCP PDU and PDCP header are octet-aligned;
- PDCP header can be either 1 or 2 bytes long.

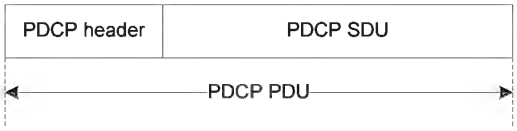


Figure 6.3.2-1: PDCP PDU Structure

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The structures for control PDCP PDUs and for control plane PDCP data PDUs are specified in [15].

6.4 Void

7 RRC

This subclause provides an overview on services and functions provided by the RRC sublayer.

7.1 Services and Functions

The main services and functions of the RRC sublayer include:

- Broadcast of System Information related to the non-access stratum (NAS);
- Broadcast of System Information related to the access stratum (AS);
- Paging;
- Establishment, maintenance and release of an RRC connection between the UE and E-UTRAN including:
  - Allocation of temporary identifiers between UE and E-UTRAN;
  - Configuration of signalling radio bearer(s) for RRC connection:
    - Low priority SRB and high priority SRB.
- Security functions including key management;
- Establishment, configuration, maintenance and release of point to point Radio Bearers;
- Mobility functions including:
  - UE measurement reporting and control of the reporting for inter-cell and inter-RAT mobility;
  - Handover;
  - UE cell selection and reselection and control of cell selection and reselection;
  - Context transfer at handover.
- QoS management functions;
- UE measurement reporting and control of the reporting;
- NAS direct message transfer to/from NAS from/to UE.

7.2 RRC protocol states & state transitions

RRC uses the following states:

- **RRC_IDLE**:
  - PLMN selection;
  - DRX configured by NAS;
  - Broadcast of system information;
  - Paging;
  - Cell re-selection mobility;

- The UE shall have been allocated an id which uniquely identifies the UE in a tracking area;
- No RRC context stored in the eNB.

- **RRC_CONNECTED**:
  - UE has an E-UTRAN-RRC connection;
  - UE has context in E-UTRAN;
  - E-UTRAN knows the cell which the UE belongs to;
  - Network can transmit and/or receive data to/from UE;
  - Network controlled mobility (handover and inter-RAT cell change order to GERAN with NACC);
  - Neighbour cell measurements;
  - At PDCP/RLC/MAC level:
    - UE can transmit and/or receive data to/from network;
    - UE monitors control signalling channel for shared data channel to see if any transmission over the shared data channel has been allocated to the UE;
    - UE also reports channel quality information and feedback information to eNB;
    - DRX period can be configured according to UE activity level for UE power saving and efficient resource utilization. This is under control of the eNB.

7.3 Transport of NAS messages

The AS provides reliable in-sequence delivery of NAS messages in a cell. During handover, message loss or duplication of NAS messages can occur.

In E-UTRAN, NAS messages are either concatenated with RRC messages or carried in RRC without concatenation.

In DL, when an EPS bearer establishment or release procedure is triggered, the NAS message should normally be concatenated with the associated RRC message. When the EPS bearer is modified and when the modification also depends on a modification of the radio bearer, the NAS message and associated RRC message should normally be concatenated. Concatenation of DL NAS with RRC message is not allowed otherwise. In uplink concatenation of NAS messages with RRC message is used only for transferring the initial NAS message during connection setup. Initial Direct Transfer is not used in E-UTRAN and no NAS message is concatenated with RRC connection request.

Multiple NAS messages can be sent in a single downlink RRC message during EPS bearer establishment or modification. In this case, the order of the NAS messages in the RRC message shall be kept the same as that in the corresponding S1-AP message in order to ensure the in-sequence delivery of NAS messages.

NOTE: NAS messages are integrity protected and ciphered by PDCP, in addition to the integrity protection and ciphering performed by NAS.

7.4 System Information

System information is divided into the *MasterInformationBlock* (MIB) and a number of *SystemInformationBlocks* (SIBs):

- *MasterInformationBlock* defines the most essential physical layer information of the cell required to receive further system information;
- *SystemInformationBlockType1* contains information relevant when evaluating if a UE is allowed to access a cell and defines the scheduling of other system information blocks;
- *SystemInformationBlockType2* contains common and shared channel information;

- *SystemInformationBlockType3* contains cell re-selection information, mainly related to the serving cell;
- *SystemInformationBlockType4* contains information about the serving frequency and intra-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
- *SystemInformationBlockType5* contains information about other E-UTRA frequencies and inter-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
- *SystemInformationBlockType6* contains information about UTRA frequencies and UTRA neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
- *SystemInformationBlockType7* contains information about GERAN frequencies relevant for cell re-selection (including cell re-selection parameters for each frequency);
- *SystemInformationBlockType8* contains information about CDMA2000 frequencies and CDMA2000 neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
- *SystemInformationBlockType9* contains a home eNB identifier (HNBID);
- *SystemInformationBlockType10* contains an ETWS primary notification;
- *SystemInformationBlockType11* contains an ETWS secondary notification.

The MIB is mapped on the BCCH and carried on BCH while all other SI messages are mapped on the BCCH and dynamically carried on DL-SCH where they can be identified through the SI-RNTI (System Information RNTI). Both the MIBand *SystemInformationBlockType1*use a fixed schedule with a periodicity of 40 and 80 ms respectively while the scheduling of other SI messages is flexible and indicated by *SystemInformationBlockType1*.

The eNB may schedule DL-SCH transmissions concerning logical channels other than BCCH in the same subframe as used for BCCH. The minimum UE capability restricts the BCCH mapped to DL-SCH e.g. regarding the maximum rate.

The Paging message is used to inform UEs in RRC_IDLE and UEs in RRC_CONNECTED about a system information change.

System information may also be provided to the UE by means of dedicated signalling e.g. upon handover.

7.5 Void

8 E-UTRAN identities

8.1 E-UTRAN related UE identities

The following E-UTRAN related UE identities are used at cell level:

- C-RNTI: unique identification used for identifying RRC Connection and scheduling;
- Semi-Persistent Scheduling C-RNTI: unique identification used for semi-persistent scheduling;
- Temporary C-RNTI: identification used for the random access procedure;
- TPC-PUSCH-RNTI: identification used for the power control of PUSCH;
- TPC-PUCCH-RNTI: identification used for the power control of PUCCH;
- Random value for contention resolution: during some transient states, the UE is temporarily identified with a random value used for contention resolution purposes.

8.2 Network entity related Identities

The following identities are used in E-UTRAN for identifying a specific network entity [25]:

- Globally Unique MME Identity (GUMMEI): used to identify MME globally. The GUMMEI is constructed from the PLMN identity the MME belongs to, the group identity of the MME group the MME belongs to and the MME code (MMEC) of the MME within the MME group.

NOTE: a UE in ECM-IDLE establishing an RRC connection has to provide the GUMMEI of its current MME to the eNB in order for the eNB to fetch the UE context from the MME. Within the S-TMSI, one field contains the code of the MME (MMEC) that allocated the S-TMSI. The code of MME is needed to ensure that the S-TMSI remains unique in a tracking area shared by multiple MMEs.

- E-UTRAN Cell Global Identifier (ECGI): used to identify cells globally. The ECGI is constructed from the PLMN identity the cell belongs to and the Cell Identity (CI) of the cell. The included PLMN is the one given by the first PLMN entry in SIB1, according to [16].
- eNB Identifier (eNB ID): used to identify eNBs within a PLMN. The eNB ID is contained within the CI of its cells.
- Global eNB ID: used to identify eNBs globally. The Global eNB ID is constructed from the PLMN identity the eNB belongs to and the eNB ID. The MCC and MNC are the same as included in the E-UTRAN Cell Global Identifier (ECGI).
- Tracking Area identity (TAI): used to identify tracking areas. The TAI is constructed from the PLMN identity the tracking area belongs to and the TAC (Tracking Area Code) of the Tracking Area.
- CSG identity (CSG ID): used to identify a CSG within a PLMN.
- EPS Bearer ID / E-RAB ID:
  - The value of the E-RAB ID used at S1 and X2 interfaces to identify an E-RAB allocated to the UE is the same as the EPS Bearer ID value used at the Uu interface to identify the associated EPS Bearer (and also used at the NAS layer as defined in [25]).

The following identities are broadcast in every E-UTRAN cell (SIB1): CI, TAC, CSG ID (if any) and one or more PLMN identities.

9 ARQ and HARQ

E-UTRAN provides ARQ and HARQ functionalities. The ARQ functionality provides error correction by retransmissions in acknowledged mode at Layer 2. The HARQ functionality ensures delivery between peer entities at Layer 1.

9.1 HARQ principles

The HARQ within the MAC sublayer has the following characteristics:

- N-process Stop-And-Wait;
- HARQ transmits and retransmits transport blocks;
- In the downlink:
  - Asynchronous adaptive HARQ;
  - Uplink ACK/NAKs in response to downlink (re)transmissions are sent on PUCCH or PUSCH;
  - PDCCH signals the HARQ process number and if it is a transmission or retransmission;
  - Retransmissions are always scheduled through PDCCH.

- In the uplink:
  - Synchronous HARQ;
  - Maximum number of retransmissions configured per UE (as opposed to per radio bearer);
  - Downlink ACK/NAKs in response to uplink (re)transmissions are sent on PHICH;
  - HARQ operation in uplink is governed by the following principles (summarized in Table 9.1-1):
    1) Regardless of the content of the HARQ feedback (ACK or NACK), when a PDCCH for the UE is correctly received, the UE follows what the PDCCH asks the UE to do i.e. perform a transmission or a retransmission (referred to as adaptive retransmission);
    2) When no PDCCH addressed to the C-RNTI of the UE is detected, the HARQ feedback dictates how the UE performs retransmissions:
       - NACK: the UE performs a non-adaptive retransmission i.e. a retransmission on the same uplink resource as previously used by the same process;
       - ACK: the UE does not perform any UL (re)transmission and keeps the data in the HARQ buffer. A PDCCH is then required to perform a retransmission i.e. a non-adaptive retransmission cannot follow.
- Measurement gaps are of higher priority than HARQ retransmissions: whenever an HARQ retransmission collides with a measurement gap, the HARQ retransmission does not take place.

Table 9.1-1: UL HARQ Operation

HARQ feedback seen by the UE	PDCCH seen by the UE	UE behaviour
ACK or NACK	New Transmission	New transmission according to PDCCH
ACK or NACK	Retransmission	Retransmission according to PDCCH (adaptive retransmission)
ACK	None	No (re)transmission, keep data in HARQ buffer and a PDDCH is required to resume retransmissions
NACK	None	Non-adaptive retransmission

9.2 ARQ principles

The ARQ within the RLC sublayer has the following characteristics:

- ARQ retransmits RLC PDUs or RLC PDU segments based on RLC status reports;
- Polling for RLC status report is used when needed by RLC;
- RLC receiver can also trigger RLC status report after detecting a missing RLC PDU or RLC PDU segment.

9.3 Void

10 Mobility

Load balancing is achieved in E-UTRAN with redirection mechanisms (upon RRC establishment, in RRC_CONNECTED and upon RRC release) and through the usage of inter-frequency and inter-RAT absolute priorities and inter-frequency Qoffset parameters.

Measurements to be performed by a UE for mobility are classified in at least three measurement types:

- Intra-frequency E-UTRAN measurements;

- Inter-frequency E-UTRAN measurements;
- Inter-RAT measurements for UTRAN and GERAN;
- Inter-RAT measurements of CDMA2000 HRPD or 1xRTT frequencies.

For each measurement type a measurement identity is used by E-UTRAN when configuring measurements as well as by the UE when reporting results of the measurements. Measurement quantities and reporting events are considered separately for each measurement type. Measurement commands are used by E-UTRAN to order the UE to start measurements, modify measurements or stop measurements. Three reporting criteria are used: event triggered reporting, periodic reporting and event triggered periodic reporting.

10.1 Intra E-UTRAN

In E-UTRAN RRC_CONNECTED state, network-controlled UE-assisted handovers are performed and various DRX cycles are supported.

In E-UTRAN RRC_IDLE state, cell reselections are performed and DRX is supported.

10.1.1 Mobility Management in ECM-IDLE

10.1.1.1 Cell selection

The principles of PLMN selection in E-UTRA are based on the 3GPP PLMN selection principles. Cell selection is required on transition from EMM_DETACHED to EMM-REGISTERED and from ECM-IDLE or ECM-CONNECTED.

Cell selection:

- The UE NAS identifies a selected PLMN and equivalent PLMNs;
- The UE searches the E-UTRA frequency bands and for each carrier frequency identifies the strongest cell. It reads cell system information broadcast to identify its PLMN(s):
  - The UE may search each carrier in turn ('initial cell selection') or make use of stored information to shorten the search ('stored information cell selection').
- The UE seeks to identify a suitable cell; if it is not able to identify a suitable cell it seeks to identify an acceptable cell. When a suitable cell is found or if only an acceptable cell is found it camps on that cell and commence the cell reselection procedure:
  - A suitable cell is one for which the measured cell attributes satisfy the cell selection criteria; the cell PLMN is the selected PLMN, registered or an equivalent PLMN; the cell is not barred or reserved and the cell is not part of a tracking area which is in the list of 'forbidden tracking areas for roaming';
  - An acceptable cell is one for which the measured cell attributes satisfy the cell selection criteria and the cell is not barred;

Transition to RRC_IDLE:

On transition from RRC_CONNECTED to RRC_IDLE, a UE should camp on the last cell for which it was in RRC_CONNECTED or a cell/any cell of set of cells or frequency be assigned by RRC in the state transition message.

Recovery from out of coverage:

The UE should attempt to find a suitable cell in the manner described for stored information or initial cell selection above. If no suitable cell is found on any frequency or RAT the UE should attempt to find an acceptable cell.

10.1.1.2 Cell reselection

UE in RRC_IDLE performs cell reselection. The principles of the procedure are the following:

- The UE makes measurements of attributes of the serving and neighbour cells to enable the reselection process:
  - There is no need to indicate neighbouring cell in the serving cell system information to enable the UE to search and measure a cell i.e. E-UTRAN relies on the UE to detect the neighbouring cells;
  - For the search and measurement of inter-frequency neighbouring cells, only the carrier frequencies need to be indicated;
  - Measurements may be omitted if the serving cell attribute fulfils particular search or measurement criteria.
- Cell reselection identifies the cell that the UE should camp on. It is based on cell reselection criteria which involves measurements of the serving and neighbour cells:
  - Intra-frequency reselection is based on ranking of cells;
  - Inter-frequency reselection is based on absolute priorities where UE tries to camp on highest priority frequency available. Absolute priorities for reselection are provided only by the RPLMN and valid only within the RPLMN; priorities are given by the system information and valid for all UEs in a cell, specific priorities per UE can be signalled in the RRC Connection Release message. A validity time can be associated with UE specific priorities.
  - For inter-frequency neighbouring cells, it is possible to indicate layer-specific cell reselection parameters (e.g., layer specific offset). These parameters are common to all neighbouring cells on a frequency;
  - An NCL can be provided by the serving cell to handle specific cases for intra- and inter-frequency neighbouring cells. This NCL contains cell specific cell reselection parameters (e.g., cell specific offset) for specific neighbouring cells;
  - Black lists can be provided to prevent the UE from reselecting to specific intra- and inter-frequency neighbouring cells;
  - Cell reselection can be speed dependent (speed detection based on UTRAN solution);
  - Cell reselection parameters are applicable for all UEs in a cell, but it is possible to configure specific reselection parameters per UE group or per UE.

Cell access restrictions apply as for UTRAN, which consist of access class (AC) barring and cell reservation (e.g. for cells "reserved for operator use") applicable for mobiles in RRC_IDLE mode.

10.1.1.3 Void

10.1.1.4 Void

10.1.1.5 Void

10.1.2 Mobility Management in ECM-CONNECTED

The Intra-E-UTRAN-Access Mobility Support for UEs in ECM-CONNECTED handles all necessary steps for relocation/handover procedures, like processes that precede the final HO decision on the source network side (control and evaluation of UE and eNB measurements taking into account certain UE specific area restrictions), preparation of resources on the target network side, commanding the UE to the new radio resources and finally releasing resources on the (old) source network side. It contains mechanisms to transfer context data between evolved nodes, and to update node relations on C-plane and U-plane.

In E-UTRAN RRC_CONNECTED state, network-controlled UE-assisted handovers are performed and various DRX cycles are supported:

The UE makes measurements of attributes of the serving and neighbour cells to enable the process:

- There is no need to indicate neighbouring cell to enable the UE to search and measure a cell i.e. E-UTRAN relies on the UE to detect the neighbouring cells;

- For the search and measurement of inter-frequency neighbouring cells, at least the carrier frequencies need to be indicated;
- Network signals reporting criteria for event-triggered and periodical reporting;
- An NCL can be provided by the serving cell to handle specific cases for intra- and inter-frequency neighbouring cells. This NCL containa cell specific cell reselection parameters (e.g. cell specific offset) for specific neighbouring cells;
- Black lists can be provided to prevent the UE from measuring specific neighbouring cells.

Depending on whether the UE needs transmission/reception gaps to perform the relevant measurements, measurements are classified as gap assisted or non-gap assisted. A non-gap assisted measurement is a measurement on a cell that does not require transmission/reception gaps to allow the measurement to be performed. A gap assisted measurement is a measurement on a cell that does require transmission/reception gaps to allow the measurement to be performed. Gap patterns (as opposed to individual gaps) are configured and activated by RRC.

10.1.2.1 Handover

The intra E-UTRAN HO in RRC_CONNECTED state is UE assisted NW controlled HO, with HO preparation signalling in E-UTRAN:

- Part of the HO command comes from the target eNB and is transparently forwarded to the UE by the source eNB;
- To prepare the HO, the source eNB passes all necessary information to the target eNB (e.g. E-RAB attributes and RRC context);
- Both the source eNB and UE keep some context (e.g. C-RNTI) to enable the return of the UE in case of HO failure;
- UE accesses the target cell via RACH following a contention-free procedure using a dedicated RACH preamble or following a contention-based procedure if dedicated RACH preambles are not available:
  - the UE uses the dedicated preamble until the handover procedure is finished (successfully or unsuccessfully);
- If the RACH procedure towards the target cell is not successful within a certain time, the UE initiates radio link failure recovery using the best cell;
- No ROHC context is transferred at handover.

10.1.2.1.1 C-plane handling

The HO procedure is performed without EPC involvement, i.e. preparation messages are directly exchanged between the eNBs. The release of the resources at the source side during the HO completion phase is triggered by the eNB. The figure below depicts the basic handover scenario where neither MME nor Serving Gateway changes:

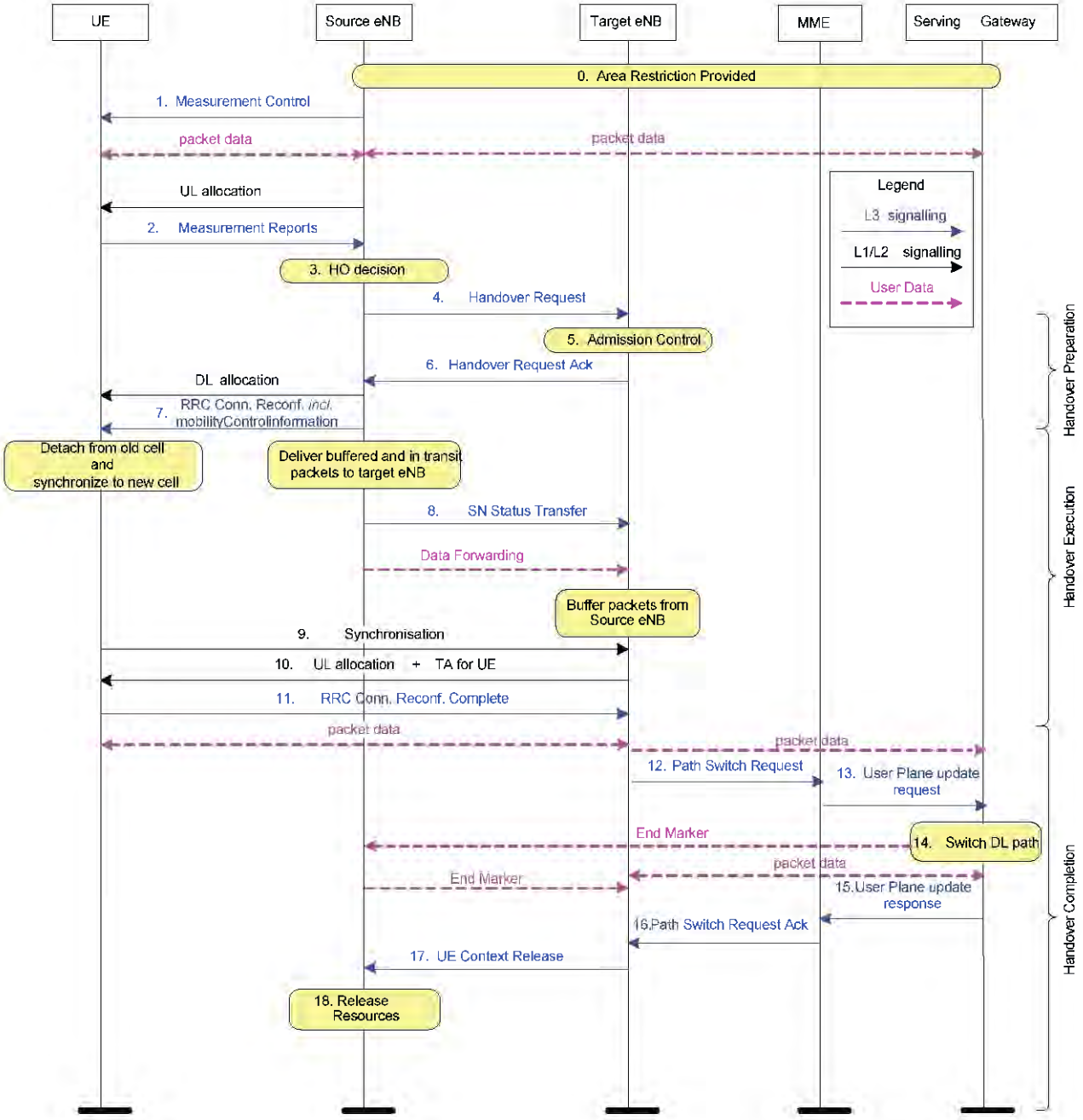


Figure 10.1.2.1.1-1: Intra-MME/Serving Gateway HO

Below is a more detailed description of the intra-MME/Serving Gateway HO procedure:

0 The UE context within the source eNB contains information regarding roaming restrictions which where provided either at connection establishment or at the last TA update.

1 The source eNB configures the UE measurement procedures according to the area restriction information. Measurements provided by the source eNB may assist the function controlling the UE's connection mobility.

2 UE is triggered to send MEASUREMENT REPORT by the rules set by i.e. system information, specification etc.

3 Source eNB makes decision based on MEASUREMENT REPORT and RRM information to hand off UE.

4 The source eNB issues a HANDOVER REQUEST message to the target eNB passing necessary information to prepare the HO at the target side (UE X2 signalling context reference at source eNB, UE S1 EPC signalling context reference, target cell ID, K_{eNB*}, RRC context including the C-RNTI of the UE in the source eNB, AS-configuration, E-RAB context and physical layer ID of the source cell + MAC for possible RLF recovery). UE X2 / UE S1 signalling references enable the target eNB to address the source eNB and the EPC. The E-RAB context includes necessary RNL and TNL addressing information, and QoS profiles of the E-RABs.

5 Admission Control may be performed by the target eNB dependent on the received E-RAB QoS information to increase the likelihood of a successful HO, if the resources can be granted by target eNB. The target eNB configures the required resources according to the received E-RAB QoS information and reserves a C-RNTI and optionally a RACH preamble. The AS-configuration to be used in the target cell can either be specified independently (i.e. an "establishment") or as a delta compared to the AS-configuration used in the source cell (i.e. a "reconfiguration").

6 Target eNB prepares HO with L1/L2 and sends the HANDOVER REQUEST ACKNOWLEDGE to the source eNB. The HANDOVER REQUEST ACKNOWLEDGE message includes a transparent container to be sent to the UE as an RRC message to perform the handover. The container includes a new C-RNTI, target eNB security algorithm identifiers for the selected security algorithms, may include a dedicated RACH preamble, and possibly some other parameters i.e. access parameters, SIBs, etc. The HANDOVER REQUEST ACKNOWLEDGE message may also include RNL/TNL information for the forwarding tunnels, if necessary.

NOTE: As soon as the source eNB receives the HANDOVER REQUEST ACKNOWLEDGE, or as soon as the transmission of the handover command is initiated in the downlink, data forwarding may be initiated.

Steps 7 to 16 provide means to avoid data loss during HO and are further detailed in 10.1.2.1.2 and 10.1.2.3.

7 The target eNB generates the RRC message to perform the handover, i.e *RRCConnectionReconfiguration* message including the *mobilityControlInformation*, to be sent by the source eNB towards the UE. The source eNB performs the necessary integrity protection and ciphering of the message. The UE receives the *RRCConnectionReconfiguration* message with necessary parameters (i.e. new C-RNTI, target eNB security algorithm identifiers, and optionally dedicated RACH preamble, target eNB SIBs, etc.) and is commanded by the source eNB to perform the HO. The UE does not need to delay the handover execution for delivering the HARQ/ARQ responses to source eNB.

8 The source eNB sends the SN STATUS TRANSFER message to the target eNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of E-RABs for which PDCP status preservation applies (i.e. for RLC AM). The uplink PDCP SN receiver status includes at least the PDCP SN of the first missing UL SDU and may include a bit map of the receive status of the out of sequence UL SDUs that the UE needs to retransmit in the target cell, if there are any such SDUs. The downlink PDCP SN transmitter status indicates the next PDCP SN that the target eNB shall assign to new SDUs, not having a PDCP SN yet. The source eNB may omit sending this message if none of the E-RABs of the UE shall be treated with PDCP status preservation.

9 After receiving the *RRCConnectionReconfiguration* message including the *mobilityControlInformation* , UE performs synchronisation to target eNB and accesses the target cell via RACH, following a contention-free procedure if a dedicated RACH preamble was indicated in the *mobilityControlInformation*, or following a contention-based procedure if no dedicated preamble was indicated. UE derives target eNB specific keys and configures the selected security algorithms to be used in the target cell.

10 The target eNB responds with UL allocation and timing advance.

11 When the UE has successfully accessed the target cell, the UE sends the *RRCConnectionReconfigurationComplete* message (C-RNTI) to confirm the handover, along with an uplink Buffer Status Report, whenever possible, to the target eNB to indicate that the handover procedure is completed for the UE. The target eNB verifies the C-RNTI sent in the *RRCConnectionReconfigurationComplete* message. The target eNB can now begin sending data to the UE.

12 The target eNB sends a PATH SWITCH message to MME to inform that the UE has changed cell.

13 The MME sends an UPDATE USER PLANE REQUEST message to the Serving Gateway.

14 The Serving Gateway switches the downlink data path to the target side. The Serving gateway sends one or more "end marker" packets on the old path to the source eNB and then can release any U-plane/TNL resources towards the source eNB.

15 Serving Gateway sends an UPDATE USER PLANE RESPONSE message to MME.

16 The MME confirms the PATH SWITCH message with the PATH SWITCH ACKNOWLEDGE message.

17 By sending UE CONTEXT RELEASE, the target eNB informs success of HO to source eNB and triggers the release of resources by the source eNB. The target eNB sends this message after the PATH SWITCH ACKNOWLEDGE message is received from the MME.

18 Upon reception of the UE CONTEXT RELEASE message, the source eNB can release radio and C-plane related resources associated to the UE context. Any ongoing data forwarding may continue.

10.1.2.1.2 U-plane handling

The U-plane handling during the Intra-E-UTRAN-Access mobility activity for UEs in ECM-CONNECTED takes the following principles into account to avoid data loss during HO:

- During HO preparation U-plane tunnels can be established between the source eNB and the target eNB. There is one tunnel established for uplink data forwarding and another one for downlink data forwarding for each E-RAB for which data forwarding is applied.
- During HO execution, user data can be forwarded from the source eNB to the target eNB. The forwarding may take place in a service and deployment dependent and implementation specific way.
  - Forwarding of downlink user data from the source to the target eNB should take place in order as long as packets are received at the source eNB from the EPC or the source eNB buffer has not been emptied.
- During HO completion:
  - The target eNB sends a PATH SWITCH message to MME to inform that the UE has gained access and MME sends a USER PLANE UPDATE REQUEST message to the Serving Gateway, the U-plane path is switched by the Serving Gateway from the source eNB to the target eNB.
  - The source eNB should continue forwarding of U-plane data as long as packets are received at the source eNB from the Serving Gateway or the source eNB buffer has not been emptied.

For **RLC-AM bearers**:

- For in-sequence delivery and duplication avoidance, PDCP SN is maintained on a bearer basis and the source eNB informs the target eNB about the next DL PDCP SN to allocate to a packet which does not have a PDCP sequence number yet (either from source eNB or from the Serving Gateway).
- For security synchronisation, HFN is also maintained and the source eNB provides to the target one reference HFN for the UL and one for the DL i.e. HFN and corresponding SN.
- In both the UE and the target eNB, a window-based mechanism is needed for duplication detection.
- The occurrence of duplicates over the air interface in the target eNB is minimised by means of PDCP SN based reporting at the target eNB by the UE. In uplink, the reporting is optionally configured on a bearer basis by the eNB and the UE should first start by transmitting those reports when granted resources in the target eNB. In downlink, the eNB is free to decide when and for which bearers a report is sent and the UE does not wait for the report to resume uplink transmission.
- The target eNB re-transmits and prioritizes all downlink PDCP SDUs forwarded by the source eNB (i.e. the target eNB should send data with PDCP SNs from X2 before sending data from S1), with the exception of PDCP SDUs of which the reception was acknowledged through PDCP SN based reporting by the UE.
- The UE re-transmits in the target eNB all uplink PDCP SDUs starting from the first PDCP SDU following the last consecutively confirmed PDCP SDU i.e. the oldest PDCP SDU that has not been acknowledged at RLC in the source, excluding the PDCP SDUs of which the reception was acknowledged through PDCP SN based reporting by the target.

For **RLC-UM bearers**:

- The PDCP SN and HFN are reset in the target eNB.
- No PDCP SDUs are retransmitted in the target eNB.
- The target eNB prioritize all downlink PDCP SDUs forwarded by the source eNB if any (i.e. the target eNB should send data with PDCP SNs from X2 before sending data from S1),.
- The UE PDCP entity does not attempt to retransmit any PDCP SDU in the target cell for which transmission had been completed in the source cell. Instead UE PDCP entity starts the transmission with other PDCP SDUs.

10.1.2.2 Path Switch

After the downlink path is switched at the Serving GW downlink packets on the forwarding path and on the new direct path may arrive interchanged at the target eNB. The target eNodeB should first deliver all forwarded packets to the UE before delivering any of the packets received on the new direct path. The method employed in the target eNB to enforce the correct delivery order of packets is outside the scope of the standard.

In order to assist the reordering function in the target eNB, the Serving GW shall send one or more "end marker" packets on the old path immediately after switching the path for each E-RAB of the UE. The "end marker" packet shall not contain user data. The "end marker" is indicated in the GTP header. After completing the sending of the tagged packets the GW shall not send any further user data packets via the old path.

Upon receiving the "end marker" packets, the source eNB shall, if forwarding is activated for that bearer, forward the packet toward the target eNB.

On detection of an "end marker" the target eNB shall discard the end marker packet and initiate any necessary processing to maintain in sequence delivery of user data forwarded over X2 interface and user data received from the serving GW over S1 as a result of the path switch.

On detection of the "end marker", the target eNB may also initiate the release of the data forwarding resource. However, the release of the data forwarding resource is implementation dependent and could also be based on other mechanisms (e.g. timer-based mechanism).

EPC may change the uplink end-point of the tunnels with Path Switch procedure. However, the EPC should keep the old GTP tunnel end-point(s) sufficiently long time in order to minimise the probability of packet losses and avoid unintentional release of respective E-RAB(s).

10.1.2.3 Data forwarding

10.1.2.3.1 For RLC-AM DRBs

Upon handover, the source eNB may forward in order to the target eNB all downlink PDCP SDUs with their SN that have not been acknowledged by the UE. In addition, the source eNB may also forward without a PDCP SN fresh data arriving over S1 to the target eNB.

NOTE: Target eNB does not have to wait for the completion of forwarding from the source eNB before it begins transmitting packets to the UE.

The source eNB discards any remaining downlink RLC PDUs. Correspondingly, the source eNB does not forward the downlink RLC context to the target eNB.

NOTE: Source eNB does not need to abort on going RLC transmissions with the UE as it starts data forwarding to the target eNB.

Upon handover, the source eNB forwards to the Serving Gateway the uplink PDCP SDUs successfully received in-sequence until the sending of the Status Transfer message to the target eNB. Then at that point of time the source eNB stops delivering uplink PDCP SDUs to the S-GW and shall discard any remaining uplink RLC PDUs. Correspondingly, the source eNB does not forward the uplink RLC context to the target eNB.

Then the source eNB shall either:

- discard the uplink PDCP SDUs received out of sequence if the source eNB has not accepted the request from the target eNB for uplink forwarding or if the target eNB has not requested uplink forwarding for the bearer during the Handover Preparation procedure,

- forward to the target eNB the uplink PDCP SDUs received out of sequence if the source eNB has accepted the request from the target eNB for uplink forwarding for the bearer during the Handover Preparation procedure.

The PDCP SN of forwarded SDUs is carried in the "PDCP PDU number" field of the GTP-U extension header. The target eNB shall use the PDCP SN if it is available in the forwarded GTP-U packet.

In-sequence delivery of upper layer PDUs during handover is based on a continuous PDCP SN and is provided by the "in-order delivery and duplicate elimination" function at the PDCP layer:

- in the downlink, the "in-order delivery and duplicate elimination" function at the UE PDCP layer guarantees in-sequence delivery of downlink PDCP SDUs;

- in the uplink, the "in-order delivery and duplicate elimination" function at the target eNB PDCP layer guarantees in-sequence delivery of uplink PDCP SDUs.

After handover, when the UE receives a PDCP SDU from the target eNB, it can deliver it to higher layer together with all PDCP SDUs with lower SNs regardless of possible gaps.

10.1.2.3.2 For RLC-UM DRBs

Upon handover, the source eNB does not forward to the target eNB downlink PDCP SDUs for which transmission had been completed in the source cell. PDCP SDUs that have not been transmitted may be forwarded. In addition, the source eNB may forward fresh downlink data arriving over S1 to the target eNB. The source eNB discards any remaining downlink RLC PDUs. Correspondingly, the source eNB does not forward the downlink RLC context to the target eNB.

Upon handover, the source eNB forwards all uplink PDCP SDUs successfully received to the Serving Gateway (i.e. including the ones received out of sequence) and discards any remaining uplink RLC PDUs. Correspondingly, the source eNB does not forward the uplink RLC context to the target eNB.

10.1.2.3.3 SRB handling

With respect to SRBs, the following principles apply at HO:

- No forwarding or retransmissions of RRC messages in the target;

- The PDCP SN and HFN are reset in the target.

10.1.2.4 Void

10.1.2.5 Void

10.1.2.6 Void

10.1.2.7 Timing Advance

In RRC_CONNECTED, the eNB is responsible for maintaining the timing advance. In some cases (e.g. during DRX), the timing advance is not necessarily always maintained and the MAC sublayer knows if the L1 is synchronised and which procedure to use to start transmitting in the uplink:

- as long as the L1 is non-synchronised, uplink transmission can only take place on PRACH.

For one UE, cases where the UL synchronisation status moves from "synchronised" to "non-synchronised" include:

- Expiration of a timer;

- Non-synchronised handover;

The value of the timer is either UE specific and managed through dedicated signalling between the UE and the eNB, or cell specific and indicated via broadcast information. In both cases, the timer is normally restarted whenever a new timing advance is given by the eNB:

- restarted to a UE specific value if any; or
- restarted to a cell specific value otherwise.

Upon DL data arrival, dedicated signature on PRACH can be allocated by the eNB to UE. When a dedicated signature on PRACH is allocated, the UE shall perform the corresponding random access procedure regardless of its L1 synchronisation status.

Timing advance updates are signalled by the eNB to the UE in MAC PDUs addressed via C-RNTI.

10.1.3 Measurements

Measurements to be performed by a UE for intra/inter-frequency mobility can be controlled by E-UTRAN, using broadcast or dedicated control. In RRC_IDLE state, a UE shall follow the measurement parameters defined for cell reselection specified by the E-UTRAN broadcast. The use of dedicated measurement control for RRC_IDLE state is possible through the provision of UE specific priorities (see sub-clause 10.2.4). In RRC_CONNECTED state, a UE shall follow the measurement configurations specified by RRC directed from the E-UTRAN (e.g. as in UTRAN MEASUREMENT_CONTROL).

Intra-frequency neighbour (cell) measurements and inter-frequency neighbour (cell) measurements are defined as follows:

- Intra-frequency neighbour (cell) measurements: Neighbour cell measurements performed by the UE are intra-frequency measurements when the current and target cell operates on the same carrier frequency. The UE shall be able to carry out such measurements without measurement gaps.
- Inter-frequency neighbour (cell) measurements: Neighbour cell measurements performed by the UE are inter-frequency measurements when the neighbour cell operates on a different carrier frequency, compared to the current cell. The UE should not be assumed to be able to carry out such measurements without measurement gaps.

Whether a measurement is non gap assisted or gap assisted depends on the UE's capability and current operating frequency. The UE determines whether a particular cell measurement needs to be performed in a transmission/reception gap and the scheduler needs to know whether gaps are needed:

- Same carrier frequency and cell bandwidths (Scenario A): an intra-frequency scenario; not measurement gap assisted.
- Same carrier frequency, bandwidth of the target cell smaller than the bandwidth of the current cell (Scenario B): an intra-frequency scenario; not measurement gap assisted.
- Same carrier frequency, bandwidth of the target cell larger than the bandwidth of the current cell (Scenario C): an intra-frequency scenario; not measurement gap assisted.
- Different carrier frequencies, bandwidth of the target cell smaller than the bandwidth of the current cell and bandwidth of the target cell within bandwidth of the current cell (Scenario D): an inter-frequency scenario; measurement gap-assisted scenario.
- Different carrier frequencies, bandwidth of the target cell larger than the bandwidth of the current cell and bandwidth of the current cell within bandwidth of the target cell (Scenario E): an inter-frequency scenario; measurement gap-assisted scenario.
- Different carrier frequencies and non-overlapping bandwidth, (Scenario F): an inter-frequency scenario; measurement gap-assisted scenario.

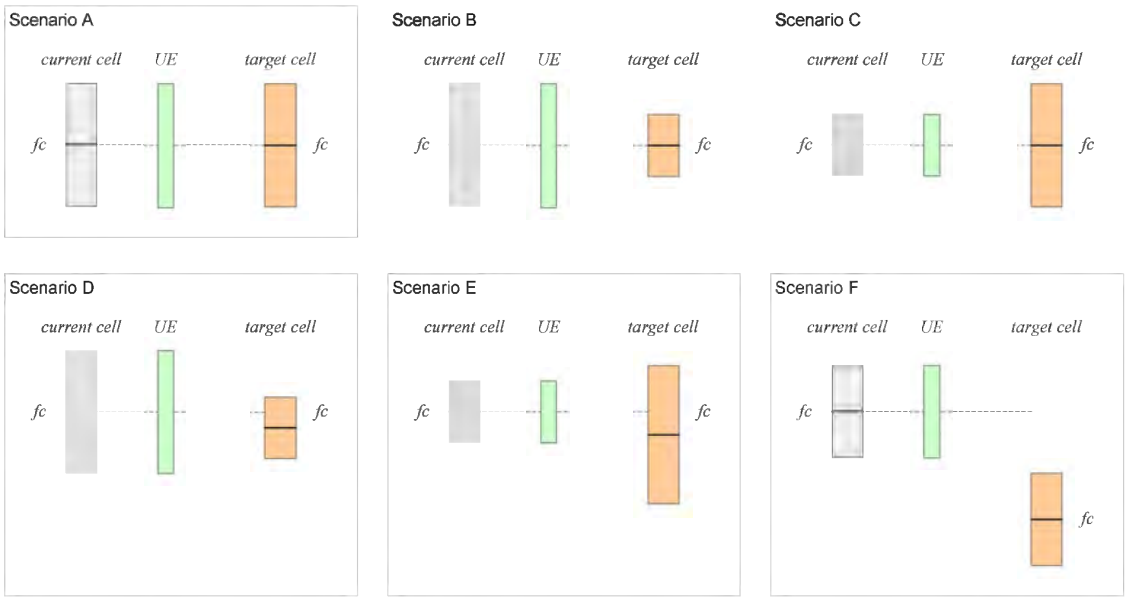


Figure 10.1.3-1: Inter and Intra-frequency measurements scenarios

Measurement gaps patterns are configured and activated by RRC.

10.1.3.1 Intra-frequency neighbour (cell) measurements

In a system with frequency reuse = 1, mobility within the same frequency layer (i.e. between cells with the same carrier frequency) is predominant. Good neighbour cell measurements are needed for cells that have the same carrier frequency as the serving cell in order to ensure good mobility support and easy network deployment. Search for neighbour cells with the same carrier frequency as the serving cell, and measurements of the relevant quantities for identified cells are needed.

NOTE: To avoid UE activity outside the DRX cycle, the reporting criteria for neighbour cell measurements should match the used DRX cycle.

10.1.3.2 Inter-frequency neighbour (cell) measurements

Regarding mobility between different frequency layers (i.e. between cells with a different carrier frequency), UE may need to perform neighbour cell measurements during DL/UL idle periods that are provided by DRX or packet scheduling (i.e. gap assisted measurements).

10.1.4 Paging and C-plane establishment

Paging groups (where multiple UEs can be addressed) are used on PDCCH:

- Precise UE identity is found on PCH;
- DRX configurable via BCCH and NAS;
- Only one subframe allocated per paging interval per UE;
- The network may divide UEs to different paging occasions in time;
- There is no grouping within paging occasion;
- One paging RNTI for PCH.

10.1.5 Random Access Procedure

The random access procedure is characterized by:

- Common procedure for FDD and TDD;
- One procedure irrespective of cell size;

The random access procedure is performed for the following five events:

- Initial access from RRC_IDLE;
- RRC Connection Re-establishment procedure;
- Handover;
- DL data arrival during RRC_CONNECTED requiring random access procedure;
  - E.g. when UL synchronisation status is 'non-synchronised';
- UL data arrival during RRC_CONNECTED requiring random access procedure;
  - E.g. when UL synchronisation status is "non-synchronised" or there are no PUCCH resources for SR available.

Furthermore, the random access procedure takes two distinct forms:

- Contention based (applicable to all five events);
- Non-contention based (applicable to only handover and DL data arrival).

Normal DL/UL transmission can take place after the random access procedure.

10.1.5.1 Contention based random access procedure

The contention based random access procedure is outlined on Figure 10.1.5.1-1 below:

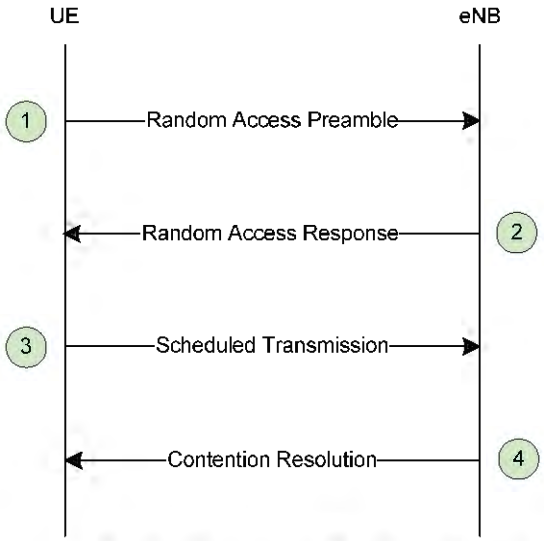


Figure 10.1.5.1-1: Contention based Random Access Procedure

The four steps of the contention based random access procedures are:

1) Random Access Preamble on RACH in uplink:
   - There are two possible groups defined and one is optional. If both groups are configured the size of message 3 and the pathloss are used to determine which group a preamble is selected from. The group to which a preamble belongs provides an indication of the size of the message 3 and the radio conditions at the UE. The preamble group information along with the necessary thresholds are broadcast on system information.
2) Random Access Response generated by MAC on DL-SCH:

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- Semi-synchronous (within a flexible window of which the size is one or more TTI) with message 1;
- No HARQ;
- Addressed to RA-RNTI on PDCCH;
- Conveys at least RA-preamble identifier, Timing Alignment information, initial UL grant and assignment of Temporary C-RNTI (which may or may not be made permanent upon Contention Resolution);
- Intended for a variable number of UEs in one DL-SCH message.

3) First scheduled UL transmission on UL-SCH:
   - Uses HARQ;
   - Size of the transport blocks depends on the UL grant conveyed in step 2 and is at least 80 bits.
   - For initial access:
     - Conveys the RRC Connection Request generated by the RRC layer and transmitted via CCCH;
     - Conveys at least NAS UE identifier but no NAS message;
     - RLC TM: no segmentation;
   - For RRC Connection Re-establishment procedure:
     - Conveys the RRC Connection Re-establishment Request generated by the RRC layer and transmitted via CCCH;
     - RLC TM: no segmentation;
     - Does not contain any NAS message.
   - After handover, in the target cell:
     - Conveys the ciphered and integrity protected RRC Handover Confirm generated by the RRC layer and transmitted via DCCH;
     - Conveys the C-RNTI of the UE (which was allocated via the Handover Command);
     - Includes an uplink Buffer Status Report when possible.
   - For other events:
     - Conveys at least the C-RNTI of the UE.
4) Contention Resolution on DL:
   - Early contention resolution shall be used i.e. eNB does not wait for NAS reply before resolving contention
   - Not synchronised with message 3;
   - HARQ is supported;
   - Addressed to:
     - The Temporary C-RNTI on PDCCH for initial access and after radio link failure;
     - The C-RNTI on PDCCH for UE in RRC_CONNECTED;
   - HARQ feedback is transmitted only by the UE which detects its own UE identity, as provided in message 3, echoed in the Contention Resolution message;
   - For initial access and RRC Connection Re-establishment procedure, no segmentation is used (RLC-TM).

The Temporary C-RNTI is promoted to C-RNTI for a UE which detects RA success and does not already have a C-RNTI; it is dropped by others. A UE which detects RA success and already has a C-RNTI, resumes using its C-RNTI.

10.1.5.2 Non-contention based random access procedure

The non-contention based random access procedure is outlined on Figure 10.1.5.2-1 below:

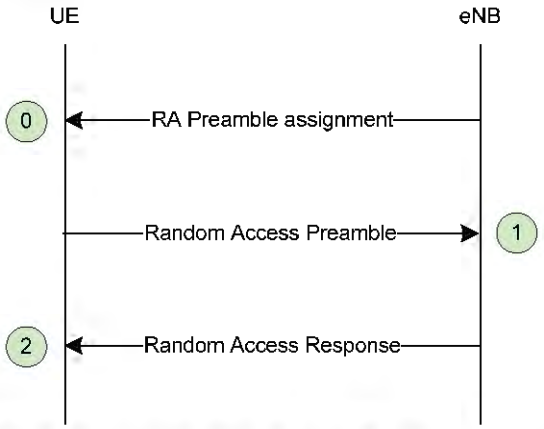


Figure 10.1.5.2-1: Non-contention based Random Access Procedure

The three steps of the non-contention based random access procedures are:

0) Random Access Preamble assignment via dedicated signalling in DL:
   - eNB assigns to UE a non-contention Random Access Preamble (a Random Access Preamble not within the set broadcasted on BCH).
   - Signalled via:
     - HO command generated by target eNB and sent via source eNB for handover;
     - PDCCH in case of DL data arrival.
1) Random Access Preamble on RACH in uplink:
   - UE transmits the assigned non-contention Random Access Preamble.
2) Random Access Response on DL-SCH:
   - Semi-synchronous (within a flexible window of which the size is one or more TTI) with message 1;
   - No HARQ;
   - Addressed to RA-RNTI on PDCCH;
   - Conveys at least:
     - Timing Alignment information and initial UL grant for handover;
     - Timing Alignment information for DL data arrival;
     - RA-preamble identifier.
     - Intended for one or multiple UEs in one DL-SCH message.

10.1.5.3 Interaction model between L1 and L2/3 for Random Access Procedure

Random access procedure described above is modelled in Figure 10.1.5.3-1 below from L1 and L2/3 interaction point of view. L2/L3 receives indication from L1 whether ACK is received or DTX is detected after indication of Random Access Preamble transmission to L1. L2/3 indicates L1 to transmit first scheduled UL transmission (RRC Connection Request in case of initial access) if necessary or Random Access Preamble based on the indication from L1.

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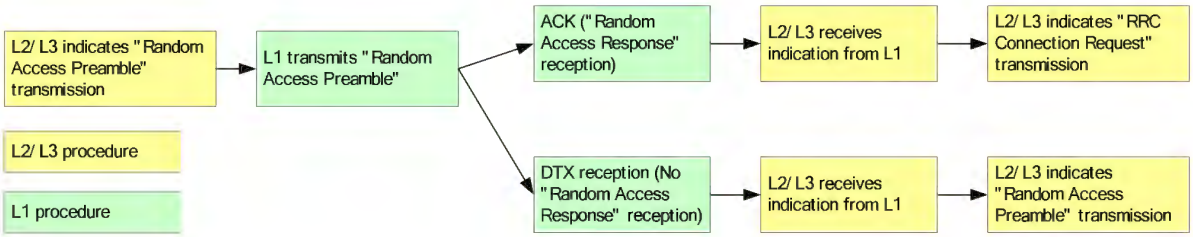


Figure 10.1.5.3-1: Interaction model between L1 and L2/3 for Random Access Procedure

10.1.6 Radio Link Failure

Two phases governs the behaviour associated to radio link failure as shown on Figure 10.1.6-1:

- First phase:
  - started upon radio problem detection;
  - leads to radio link failure detection;
  - no UE-based mobility;
  - based on timer or other (e.g. counting) criteria (T_1).
- Second Phase:
  - started upon radio link failure detection or handover failure;
  - leads to RRC_IDLE;
  - UE-based mobility;
  - Timer based (T_2).

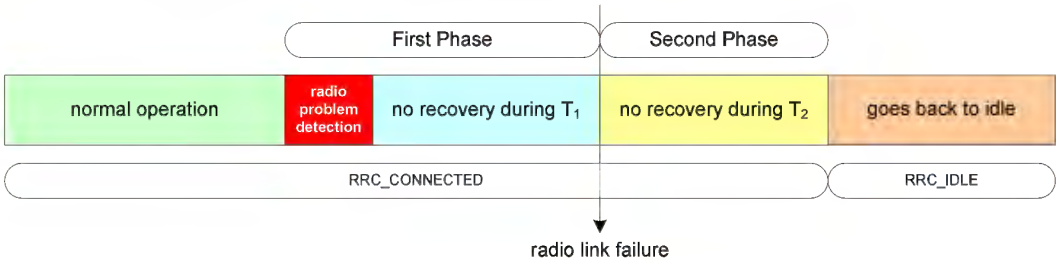


Figure 10.1.6-1: Radio Link Failure

Table 10.1.6-1 below describes how mobility is handled with respect to radio link failure:

Table 10.1.6-1: Mobility and Radio Link Failure

Cases	First Phase	Second Phase	T2 expired
UE returns to the same cell	Continue as if no radio problems occurred	Activity is resumed by means of explicit signalling between UE and eNB	Go via RRC_IDLE
UE selects a different cell from the same eNB	N/A	Activity is resumed by means of explicit signalling between UE and eNB	Go via RRC_IDLE
UE selects a cell of a prepared eNB (NOTE)	N/A	Activity is resumed by means of explicit signalling between UE and eNB	Go via RRC_IDLE
UE selects a cell of a different eNB that is not prepared (NOTE)	N/A	Go via RRC_IDLE	Go via RRC_IDLE
NOTE: a prepared eNB is an eNB which has admitted the UE during an earlier executed HO preparation phase.			

In the Second Phase, in order to resume activity and avoid going via RRC_IDLE when the UE returns to the same cell or when the UE selects a different cell from the same eNB, or when the UE selects a cell from a different eNB, the following procedure applies:

- The UE stays in RRC_CONNECTED;
- The UE accesses the cell through the random access procedure;
- The UE identifier used in the random access procedure for contention resolution (i.e. C-RNTI of the UE in the cell where the RLF occurred + physical layer identity of that cell + MAC based on the keys of that cell) is used by the selected eNB to authenticate the UE and check whether it has a context stored for that UE:
  - If the eNB finds a context that matches the identity of the UE, it indicates to the UE that its connection can be resumed;
  - If the context is not found, RRC connection is released and UE initiates procedure to establish new RRC connection. In this case UE is required to go via RRC_IDLE.

10.1.7 Radio Access Network Sharing

E-UTRAN shall support radio access network sharing based on support for multi-to-multi relationship between E-UTRAN nodes and EPC nodes (S1-flex).

If the E-UTRAN is shared by multiple operators, the system information broadcasted in each shared cell contains the PLMN-id of each operator (up to 6) and a single tracking area code (TAC) valid within all the PLMNs sharing the radio access network resources.

The UE shall be able to read up to 6 PLMN-ids, to select one of the PLMN-ids at initial attachment and to indicate this PLMN-id to the E-UTRAN in subsequent instances of the Random Access procedures (e.g. as defined in subclause 10.1.5). The E-UTRAN shall select an appropriate MME for the PLMN indicated by the UE. Once attached to an MME, the UE shall be able to indicate the allocated MME in subsequent instances of the Random Access procedures. The indication of the allocated MMEC is contained in the temporary UE identity.

Handling of area restrictions for UE in ECM-CONNECTED shall follow the principles specified in sub-clause 10.4.

10.1.8 Handling of Roaming and Area Restrictions for UEs in ECM-CONNECTED

Handling of roaming/area restrictions and handling of subscription specific preferences in ECM-CONNECTED is performed in the eNB based on information provided by the EPC over the S1 interface.

10.2 Inter RAT

Service-based redirection between GERAN / UTRAN and E-UTRAN is supported in both directions. This should not require inter-RAT reporting in RRC CONNECTION REQUEST.

10.2.1 Cell reselection

A UE in RRC_IDLE performs cell reselection. The principles of this procedure are as follows:

- The UE makes **measurements** of attributes of the serving and neighbour cells to enable the reselection process:
  - For a UE to search and measure neighbouring GERAN cells, the ARFCNs of the BCCH carriers need to be indicated in the serving cell system information (i.e., an NCL). The NCL does not contain BSICs or cell specific offsets and Qrxlevmin is given per frequency band.
  - For a UE to search and measure neighbouring UTRAN cells, the serving cell can indicate an NCL containing a list of carrier frequencies and scrambling codes.
  - Measurements may be omitted if the serving cell attribute fulfils particular search or measurement criteria.
- **Cell reselection** identifies the cell that the UE should camp on. It is based on cell reselection criteria which involves measurements of the serving and neighbour cells:
  - Inter-RAT reselection is based on absolute priorities where UE tries to camp on highest priority RAT available. Absolute priorities for inter-RAT reselection are provided only by the RPLMN and valid only within the RPLMN; priorities are given by the system information and valid for all UEs in a cell, specific priorities per UE can be signalled in the RRC Connection Release message. A validity time can be associated with UE specific priorities.
  - It should be possible to prevent the UE from reselecting to specific detected neighbouring cells;
  - The UE is allowed to "leave" the source E-UTRAN cell to read the target GERAN cell broadcast, in order to determine its "suitability", prior to completing the cell reselection;
  - Cell reselection can be speed dependent (speed detection based on UTRAN solution);

Cell access restrictions apply as for UTRAN, which consist of access class (AC) barring and cell reservation (e.g. for cells "reserved for operator use") applicable for mobiles in RRC_IDLE mode.

When performing cell reselection while the UE is camped on another RAT, the principles of this procedure are as follows:

- The UE measures attributes of the E-UTRA neighbouring cells:
  - Only the carrier frequencies need to be indicated to enable the UE to search and measure E-UTRA neighbouring cells;
- Cell reselection identifies the cell that the UE should camp on. It is based on cell reselection criteria which involves measurements of the serving and neighbour cells:
  - For E-UTRA neighbouring cells, there is no need to indicate cell-specific cell reselection parameters i.e. these parameters are common to all neighbouring cells on an E-UTRA frequency;
- Cell reselection parameters are applicable to all UEs in a cell, but it is possible to configure specific reselection parameters per UE group or per UE.
- It should be possible to prevent the UE from reselecting to specific detected neighbouring cells.

10.2.2 Handover

Inter RAT HO is designed so that changes to GERAN and UTRAN are minimised. This can be done by following the principles specified for GERAN to/from UTRAN intersystem HO. In particular the following principles are applied to E-UTRAN Inter RAT HO design:

1. Inter RAT HO is network controlled through source access system. The source access system decides about starting the preparation and provides the necessary information to the target system in the format required by the target system. That is, the source system adapts to the target system. The actual handover execution is decided in the source system.

2. Inter RAT HO is backwards handover, i.e. radio resources are prepared in the target 3GPP access system before the UE is commanded by the source 3GPP access system to change to the target 3GPP access system.

3. To enable backwards handover, and while RAN level interfaces are not available, a control interface exists in CN level. In Inter RAT HO involving E-UTRAN access, this interface is between 2G/3G SGSN and corresponding MME/Serving Gateway.

4. The target access system will be responsible for giving exact guidance for the UE on how to make the radio access there (this includes radio resource configuration, target cell system information etc.). This information is given during the handover preparation and should be transported completely transparently through the source access system to the UE.

5. Mechanisms for avoiding or mitigating the loss of user data (i.e. forwarding) can be used until the 3GPP Anchor determines that it can send DL U-plane data directly to the target system.

6. The handover procedure should not require any UE to CN signalling in order for data to start to flow in the target system. This requires that the security context, UE capability context and QoS context is transferred (or translated) within the network between source and target system.

7. Similar handover procedure should apply for handovers of both real time and non-real time services.

8. Similar handover procedure should apply for both Inter RAT Handover and intra-LTE Handover with EPC node change.

9. Network controlled mobility is supported even if no prior UE measurements have been performed on the target cell and/or frequency i.e. 'blind HO' is supported.

10.2.2a Inter-RAT cell change order to GERAN with NACC

For interworking towards GERAN, inter-RAT cell change order with NACC is supported even if no prior UE measurements have been performed on the system i.e. 'blind NACC' is supported.

10.2.2b Inter-RAT handovers from E-UTRAN

10.2.2b.1 Data forwarding

10.2.2b.1.1 For RLC-AM bearers

Upon handover, the eNB may forward all downlink PDCP SDUs that have not been acknowledged by the UE, or all downlink PDCP SDUs that have not been transmitted to the UE, to the target node. In addition, the eNB may forward fresh data arriving over S1 to the target node.

NOTE: Any assigned PDCP SNs are not forwarded because of PDCP reset.

NOTE: Target node does not have to wait for the completion of forwarding from the eNB before it begins transmitting packets to the UE.

The eNB discards any remaining downlink RLC PDUs.

Upon handover, all successfully received PDCP SDUs are delivered to the upper layers in the UE.

NOTE: eNB does not need to abort ongoing RLC transmissions with the UE as it starts data forwarding to the target node.

Upon handover, the eNB may forward uplink PDCP SDUs successfully received to the Serving Gateway and shall discard any remaining uplink RLC PDUs.

Correspondingly, the eNB does not forward the downlink and uplink RLC context.

For the uplink, the UE transmits over the target RAT from the first PDCP SDU for which transmission has not been attempted in the source cell.

In-sequence delivery of upper layer PDUs during handover is not guaranteed.

10.2.2b.1.2 For RLC-UM bearers

Upon handover, the eNB does not forward to the target node downlink PDCP SDUs for which transmission had been completed in the source cell. PDCP SDUs that have not been transmitted may be forwarded. In addition, the eNB may forward fresh data arriving over S1 to the target node. The eNB discards any remaining downlink RLC PDUs.

Upon handover, all successfully received PDCP SDUs are delivered to the upper layers in the UE.

Upon handover, the eNB may forward all uplink PDCP SDUs successfully received to the Serving Gateway and discards any remaining uplink RLC PDUs.

For the uplink, the UE transmits over the target RAT from the first PDCP SDU for which transmission has not been attempted in the source cell.

Correspondingly, the eNB does not forward the downlink and uplink RLC context.

10.2.3 Measurements

10.2.3.1 Inter-RAT handovers from E-UTRAN

Measurements to be performed by a UE for inter-RAT mobility can be controlled by E-UTRAN, using broadcast or dedicated control. In RRC_CONNECTED state, a UE shall follow the measurement parameters specified by RRC directed from the E-UTRAN (e.g. as in UTRAN MEASUREMENT_CONTROL).

UE performs inter-RAT neighbour cell measurements during DL/UL idle periods that are provided by the network through suitable DRX/DTX period or packet scheduling if necessary.

10.2.3.2 Inter-RAT handovers to E-UTRAN

From UTRAN, UE performs E-UTRAN measurements by using idle periods created by compressed mode (CELL_DCH) or DRX (other states except CELL_FACH).

From GERAN, E-UTRAN measurements are performed in the same way as WCDMA measurements for handover to UTRAN: E-UTRAN measurements are performed in GSM idle frames in a time multiplexed manner. However, it should be discussed with GERAN how to ensure that inter-RAT measurements do not take too much measurement time, while the requested 3GPP inter-RAT measurements can be performed well enough.

Design constraints of 3GPP inter-RAT measurements should be considered when L1 details of E-UTRAN concept are defined.

10.2.3.3 Inter-RAT cell reselection from E-UTRAN

In RRC_IDLE state, a UE shall follow the measurement parameters specified by the E-UTRAN broadcast (as in UTRAN SIB). The use of dedicated measurement control is possible through the provision of UE specific priorities (see sub-clause 10.2.4).

10.2.3.4 Limiting measurement load at UE

Introduction of E-UTRA implies co-existence of various UE capabilities. Each UE may support different combinations of RATs, e.g., E-UTRA, UTRA, GSM, and non-3GPP RATs, and different combinations of frequency bands, e.g., 800 MHz, 1.7 GHz, 2 GHZ, etc. Despite such heterogeneous environment, the measurement load at UE should be minimised. To limit the measurement load and the associated control load:

- E-UTRAN can configure the RATs to be measured by UE;
- The number of measurement criteria (event and periodic reporting criteria) should be limited (as in TS 25.133 subclause 8.3.2 [7]);

- E-UTRAN should be aware of the UE capabilities for efficient measurement control, to prevent unnecessary waking up of the measurement entity;
- Blind HO (i.e., HO without measurement reports from UE) is possible.

10.2.4 Network Aspects

Inter-frequency/inter-RAT UE based mobility relies on a 'priority based scheme', where the network configures a list of RATs/frequencies to be taken as basis for UE"s inter-frequency/inter-RAT cell reselection decisions in priority order. E-UTRAN cells can enable inter-frequency/inter-RAT cell reselection by broadcasting a common priority valid for all UEs in a given cell in addition to other inter-frequency/inter-RAT information.

NOTE: The same principles apply in UTRAN.

These common priorities can be overwritten by E-UTRAN through dedicated signalling to individual UEs at RRC_CONNECTED to RRC_IDLE transition.

NOTE: In order to have consistent inter-RAT operation, the same principles apply to inter-RAT reselection to E-UTRAN. For UTRAN this includes also the transitions within RRC_CONNECTED state from CELL_DCH to CELL_PCH and URA_PCH.

Setting dedicated priorities by E-UTRAN can be based on subscription related information provided by the MME.

NOTE: The same principle have been taken as a working assumption in UTRAN (awaiting for SA2 decision on feasibility of providing subscription related information by the CN).

10.3 Mobility between E-UTRAN and Non-3GPP radio technologies

10.3.1 UE Capability Configuration

A UE shall be able to communicate with the E-UTRAN about its radio access capability, such as the system (including the release and frequency band) it supports and it"s receive and transmit capabilities (single/dual radio, dual receiver). UE shall transfer its capability about other radio technologies over E-UTRAN using the same procedure used to carry its E-UTRAN radio capability.

Since the 1xRTT CSfallback procedures are triggered by the UE, or the 1xRTT network, there is no need for the eNB to know the UE 1xRTT CSfallback capability.

10.3.2 Mobility between E-UTRAN and cdma2000 network

This section describes the E-UTRAN mechanisms to support idle and active mode mobility between E-UTRAN and cdma2000 HRPD or 1xRTT. The overall system is described in [17].

10.3.2.1 Tunnelling of cdma2000 Messages over E-UTRAN between UE and cdma2000 Access Nodes

In order to efficiently support handover procedures when on E-UTRAN with a cdma2000 target system, cdma2000 messages are sent transparently to the target system over the E-UTRAN, with the eNB and MME acting as relay points.

To support the MME in its selection of the correct target system node to which it should route an Uplink tunnelled message and to provide the target system with information that is needed to resolve technology-specific measurement information (RouteUpdate and pilot strength measurements) that are delivered to the cdma2000 system each eNB cell is associated with a cdma2000 HRPD SectorID and/or with a cdma2000 1xRTT SectorID (generically referred to as cdma2000 reference cellid). This cdma2000 reference cellid is provided by the eNB to the MME using the cdma2000 message transfer capability over S1-AP and forwarded to the target system via the S101 interface and corresponding interface to the cdma2000 1xRTT system.

Tunnelling is achieved over the E-UTRAN radio interface by encapsulating tunnelled cdma2000 messages in the UL Information Transfer (for pre-registration signalling) or UL Handover Preparation transfer (for handover signalling) and DL Information Transfer RRC messages (e.g., similar to UMTS Uplink/Downlink Direct Transfer). The reason for

using different UL transfer messages is so that the UL Handover Preparation transfer messages can use a higher priority signalling radio bearer. For the UL/DL Information Transfer messages a specific IE in these RRC messages is used to identify the type of information contained in the message (e.g., NAS, TunneledMsg). Additionally if the message is carrying a tunnelled message, an additional IE is included to carry cdma2000 specific RRC Tunnelling Procedure Information (e.g. RAT type).

AS level security will be applied for these UL Information Transfer / UL Handover Preparation Transfer and DL Information Transfer RRC messages as normal but there is no NAS level security for these tunnelled cdma2000 messages.

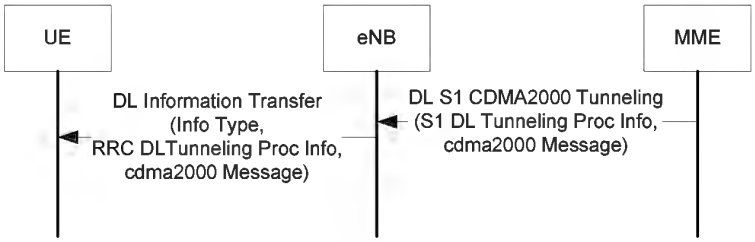


Figure 10.3.2.1-1: Downlink Direct Transfer

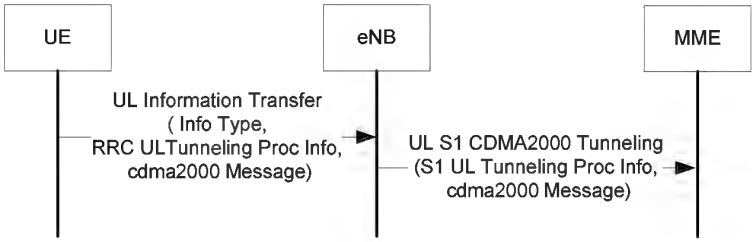


Figure 10.3.2.1-2: Uplink Direct Transfer

Tunnelling to the MME is achieved over the S1-MME interface by encapsulating the tunnelled cdma2000 message in a new S1 CDMA tunneling messages. These S1 messages carry in addition to the tunneled message some additional cdma2000 specific IEs (e.g. cdma2000 Reference Cell Id, RAT type, cdma2000 message type).

10.3.2.2 Mobility between E-UTRAN and HRPD

10.3.2.2.1 Mobility from E-UTRAN to HRPD

10.3.2.2.1.1 HRPD System Information Transmission in E-UTRAN

The HRPD system information block (SIB) shall be sent on the E-UTRAN BCCH. The UE shall monitor the E-UTRAN BCCH during the RRC_IDLE and RRC_CONNECTED modes to retrieve the HRPD system information for the preparation of cell reselection or handover from the E-UTRAN to HRPD system. HRPD system information may also be provided to the UE by means of dedicated signalling. The HRPD system information contains HRPD neighbouring cell information, cdma timing information, as well as information controlling the HRPD pre-registration.

10.3.2.2.1.2 Measuring HRPD from E-UTRAN

Measurement events and parameters for HRPD measurements are to be aligned with those defined in section 10.2.3.

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10.3.2.2.1.2.1 Idle Mode Measurement Control

UE shall be able to make measurements on the HRPD cells in RRC_IDLE mode to perform cell re-selection.

The intra-3GPP inter-RAT idle mode measurement control is re-used to control the idle mode measurements on HRPD. The UE performs measurement on HRPD when the signal quality from E-UTRAN serving cell falls below a given threshold.

10.3.2.2.1.2.2 Active Mode Measurement Control

In RRC_CONNECTED mode, the UE shall perform radio measurements on the HRPD network when directed by the E-UTRAN network. The network provides the required HRPD neighbour cell list information and measurement controls to the UE through dedicated RRC signalling. When needed the eNB is responsible for configuring and activating the HRPD measurements on the UE via the dedicated RRC signalling message. Periodic and event-triggered measurements are supported.

For single-radio terminals, measurement gaps are needed to allow the UE to switch into the HRPD network and do radio measurements. These measurement gaps are network-controlled. The eNB is responsible for configuring the gap pattern and providing it to the UE through RRC dedicated signalling. Terminals with a dual receiver perform measurements on HRPD neighbour cells without tuning away from the E-UTRAN network. No DL gap patterns will be required for UEs which are capable of simultaneous reception on the involved frequency bands. No UL gap patterns will be required for UEs which are capable simultaneous transmission in one access and measuring on another access.

10.3.2.2.1.2.3 Active Mode Measurement

In RRC_CONNECTED mode, the UE measures the strengths of each of the HRPD neighbour cells and reports them in an RRC message.

10.3.2.2.1.3 Pre-registration to HRPD Procedure

Pre-registration allows a UE to establish a presence with an HRPD system in advance of a cell re-selection or handover. E-UTRAN network instructs the UE whether the pre-registration is needed over broadcast channel and in a dedicated RRC message.

The signalling procedure is transparent to E-UTRAN network. In the pre-registration to HRPD, messages shall be tunnelled inside RRC and S1-AP messages between the UE and MME and in a generic "transfer" message between source MME and target accesss network.

The UE is responsible for maintaining the HRPD context e.g. by performing periodic re-registrations if needed. The UE will use pre-registration zone information (including the current HRPD Pre-registration Zone and a list of HRPD Secondary Pre-registration Zone ID) to decide whether a re-registration shall be performed. A dual-receiver UE can ignore the parameter. E-UTRAN will provide the pre-registration zone information on the E-UTRAN system information broadcast channel or dedicated RRC signalling (unless it is determined that the UE will read the E-UTRAN system information broadcast channel in RRC_CONNECTED). Re-registrations are only allowed in areas where pre-registration is requested.

The managing of pre-registration and re-registration is handled by HRPD upper layer. The UE should indicate if it is pre-registered when sending measurement reports on cdma2000 cells.

10.3.2.2.1.4 E-UTRAN to HRPD Cell Re-selection

For the "Optimized Idle-mode Mobility" in [19], the pre-condition for cell re-selection from E-UTRAN to HRPD is that the UE has previously established a presence in the target HRPD network, either through the pre-registration procedure or previous HRPD attachment.

For the "Non-optimized Handover" in [19], the above pre-condition does not apply.

The UE performs Cell re-selection to HRPD while in RRC_IDLE.

Cell reselection from E-UTRAN to HRPD should be aligned with 3GPP inter RAT cell reselection mechanism.

10.3.2.2.1.5 E-UTRAN to HRPD Handover

The pre-condition for the E-UTRAN to HRPD Handover procedure is that the UE is attached in the E-UTRAN network in E-UTRAN_ACTIVE state and has pre-registered with the HRPD network. Based on measurement reports received from the UE the eNB initiates a handover by sending an RRC HANDOVER FROM E-UTRA PREPARATION REQUEST message to the UE to indicate to the UE that it should begin the handover procedure. This message shall

include the specified target RAT type and any cdma2000 specific HRPD parameters needed by the UE to create the appropriate HRPD messages needed to request a connection. Upon reception of this message the UE should begin handover signalling towards the HRPD access. The HRPD handover signalling is tunnelled through E-UTRAN between the UE and HRPD network. These HRPD parameters and HRPD messages are transparent to E-UTRAN. The set of the required HRPD parameters are out of scope of this specification.

The messages are transferred inside RRC transfer messages and S1 CDMA2000 tunneling messages. The MME will, based on indication provided by the HRPD network, get information about if the handover succeeded or failed making it possible for the MME set the handover status in the S1 CDMA2000 tunneling messages (e.g. handover success, handover failure). In case the handover succeeded E-UTRAN will include the tunnelled 'CDMA2000 handover command', which will be sent to the UE, inside the RRC MOBILITY FROM E-UTRA message.

The UE can continue to send and receive data on the E-UTRAN radio until it receives the RRC MOBILITY FROM E-UTRA message including a tunnelled 'CDMA2000 handover command'. After this message is received by the UE, the UE shall leave the E-UTRAN radio and start acquiring the HRPD traffic channel. The HRPD handover signalling is tunnelled between the UE and HRPD network.

10.3.2.2.2 Mobility from HRPD to E-UTRAN

Mobility from HRPD to E-UTRAN has no impact on the E-UTRAN.

10.3.2.3 Mobility between E-UTRAN and cdma2000 1xRTT

10.3.2.3.1 Mobility from E-UTRAN to cdma2000 1xRTT

10.3.2.3.1.1 cdma2000 1xRTT System Information Transmission in E-UTRAN

The cdma2000 1xRTT system information block (SIB) shall be sent on E-UTRAN BCCH. The UE shall monitor the E-UTRAN BCCH during the LTE_IDLE and RRC_CONNECTED modes to retrieve the 1xRTT system information for the preparation of handover from the E-UTRAN to cdma 2000 1xRTT system. 1xRTT system information may also be provided to the UE by means of dedicated signalling. The 1xRTT system information contains 1xRTT neighbouring cell information and cdma timing information, as well as information controlling the 1xRTT pre-registration for 1xCS Fallback.

10.3.2.3.1.2 Measuring cdma2000 1xRTT from E-UTRAN

Measurement events and parameters for 1xRTT measurements are to be aligned with those defined in section 10.2.3.

10.3.2.3.1.2.1 Idle Mode Measurement Control

UE shall be able to make measurements on the 1xRTT system cells in LTE_IDLE mode to perform cell re-selection. UE shall perform cdma2000 1xRTT neighbour cell measurements during DRX periods, between paging occasions.

The intra-3GPP inter-RAT idle mode measurement control is re-used to control the idle mode measurements on cdma2000 1xRTT. The UE performs measurement on cdma2000 1xRTT when the signal quality from E-UTRAN serving cell falls below a given threshold.

10.3.2.3.1.2.2 Active Mode Measurement Control

In the E-UTRAN network, in RRC_CONNECTED mode, the UE shall perform radio measurements on the cdma2000 1xRTT network when directed by the E-UTRAN network. The network provides the required cdma2000 1xRTT neighbour cell list information and measurement controls to the UE through dedicated RRC signalling. When needed the eNB is responsible for configuring and activating the cdma2000 1xRTT measurements on the UE via the dedicated RRC signalling message. As for intra-3GPP inter-RAT measurement reporting, periodic and event-triggered measurements are supported.

For single-radio terminals, measurement gaps are needed to allow the UE to switch into the cdma2000 1xRTT network and do radio measurements. These Measurement gaps are network-controlled. The eNB is responsible for configuring the gap pattern and providing it to the UE through RRC dedicated signalling. Terminals with a dual receiver perform measurements on cdma2000 1xRTT neighbour cells without tuning away from the E-UTRAN network. No DL gap patterns will be required for UEs which are capable of simultaneous reception on the involved frequency bands. No UL gap patterns will be required for UEs which are capable simultaneous transmission in one access and measuring on another access.

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10.3.2.3.1.2.3 Active Mode Measurement

In RRC_CONNECTED mode, the UE measures the strengths of each of the cdma2000 1xRTT neighbour cells and reports them in an RRC Message.

10.3.2.3.1.3 E-UTRAN to cdma2000 1xRTT Cell Re-selection

UE performs Cell re-selection to cdma2000 1xRTT while in RRC_IDLE.

Cell reselection from E-UTRAN to 1xRTT should be aligned with 3GPP inter RAT cell reselection mechanism.

10.3.2.3.1.4 E-UTRAN to cdma2000 1xRTT Handover

In the high level procedure for handover from E-UTRAN to cdma2000 1xRTT except 1xRTT CS Fallback, registration and handover is performed directly after the handover decision has been made. Based on measurement reports received from the UE the eNB initiates a handover by sending a RRC HANDOVER FROM E-UTRA PREPARATION REQUEST message to the UE to indicate to the UE that it should begin the handover procedure. This message shall include the specified target RAT type and any cdma2000 specific 1xRTT access parameters needed by the UE to create the appropriate 1xRTT Origination Request message. The 1xRTT handover signalling is tunnelled between the UE and 1xRTT network. The 1xRTT access parameters and 1xRTT messages are transparent to E-UTRAN. The set of the required 1xRTT access parameters are out of scope of this specification.

The messages are transferred inside RRC transfer messages and S1 CDMA2000 tunneling messages. The MME will, based on indication provided by the 1xRTT network, get information about if the handover succeeded or failed making it possible for the MME set the handover status in the S1 CDMA2000 tunneling messages (e.g. handover success, handover failure). In case the handover succeeded E-UTRAN will include the tunnelled 'CDMA2000 handover command', which will be sent to the UE, inside the RRC MOBILITY FROM E-UTRA message.

The UE can continue to send and receive data on the E-UTRAN radio until it receives the RRC MOBILITY FROM E-UTRA message including a tunnelled 'CDMA2000 handover command'. After this message is received by the UE, the UE shall leave the E-UTRAN radio and start acquiring the 1xRTT traffic channel.

10.3.2.3.2 Mobility from cdma2000 1xRTT to E-UTRAN

Mobility from cdma2000 1xRTT has no impact on E-UTRAN.

10.3.2.3.3 1xRTT CS Fallback

CS fallback for 1xRTT enables the delivery of CS-domain services when a UE is being served by the E-UTRAN [23]. A CS fallback enabled terminal, while connected to the E-UTRAN may pre-register in the 1xRTT CS domain in order to use the 1xRTT access network to establish both terminating and originating 1xRTT calls in the CS domain. The 1xRTT signalling (pre-registration and Paging) between UE and CDMA network is transparent to E-UTRAN. The 1xRTT messages shall be tunnelled inside RRC and S1-AP messages between the UE and MME and in a generic "transfer" message between source MME and target 1xRTT access network.

10.3.2.3.3.1 Pre-registration Procedure for 1xRTT CSFB

Pre-registration allows a UE to establish a presence with the 1xRTT network in advance of a 1xCSfallback. E-UTRAN network instructs the UE whether the 1xRTT pre-registration is needed over broadcast channel. Before performing a 1xRTT pre-registration, the UE requests from the eNB the necessary information to perform the 1xRTT pre-registration using *CDMA2000-CSFBParametersRequest* message. The eNB provides the necessary parameters in the response *CDMA2000-CSFBParametersResponse.* These necessary parameters are pre-configured in the eNB and are transparent to E-UTRAN.

The UE is responsible for maintaining the 1xRTT context e.g. by performing periodic re-registrations if needed. The UE will use the 1xRTT pre-registration information to decide whether a re-registration shall be performed. A dual-receiver UE can ignore these parameters. Re-registrations are only allowed in areas where pre-registration is requested.

The management of the pre-registration and re-registration is handled by the 1xRTT upper layer in the UE.

10.4 Area Restrictions

Information on which area restrictions to be applied during ECM-CONNECTED state is provided by the MME at context setup over the S1 interface.

The eNB shall store the UE restriction information and use it to determine whether the UE has access to radio resources in the E-UTRAN. The source eNB should apply restriction handling when selecting a target eNB.

The available UE restriction information shall be propagated by the source eNB over X2 at intra E-UTRAN handover.

10.5 Mobility to and from CSG cells

10.5.0 Principles for idle-mode mobility with CSG cells

10.5.0.1 Intra-frequency mobility

Intra-frequency mobility in idle mode in the presence of 'allowed' CSG cells (*i.e.*, CSG cells that the UE is allowed to camp on) is based on cell ranking and reselection using the 'best cell principle': For cell ranking and reselection, the UE may ignore all CSG cells that are known by the UE to be not allowed.

10.5.0.2 Inter-frequency mobility

For cell ranking and reselection, the UE should prioritize CSG cells with CSG ID present in the UE"s allowed CSG list, irrespective of normal network configured frequency priorities.

10.5.0.3 Inter-RAT Mobility

Inter-RAT inbound mobility to E-UTRAN CSG cells is also supported by a UE autonomous search when the UE is camped on a RAT other than E-UTRAN. The UE requirements are defined in the specifications of the concerned RAT.

10.5.1 Inbound mobility to CSG cells

10.5.1.1 RRC_IDLE

Cell selection/reselection to CSG cells is based on a UE autonomous search function. The search function determines itself when/where to search, and need not be assisted by the network with information about frequencies which are dedicated to CSG cells.

To assist the search function on mixed carriers, all CSG cells on mixed carriers broadcast in system information a range of PCI values reserved by the network for use by CSG cells. Optionally also non-CSG cells on the mixed carrier can send this information in system information. The reserved PCI range is only applicable to the frequency of the PLMN where the UE received this information. The UE considers the last received reserved range of PCI values for CSG cells to be valid for a maximum of 24 hours within the entire PLMN. UE"s use of the received PCI split information is UE implementation dependent.

UE checks the suitability of CSG cells (identified by the 1 bit indicator) based on the allowed CSG list in the UE (provided by upper layers). A CSG cell is only suitable for a UE if it belongs to its allowed CSG list.

The automated searching for the CSG cells by the UE shall be disabled by the search function, if the allowed CSG list configured in the UE is empty.

In addition, manual selection of CSG cells is supported.

Cell selection/reselection to CSG cells does not require the network to provide neighbour cell information to the UE. The neighbour cell information can be provided to help the UE in specific cases, e.g. where the network wishes to trigger the UE to search for CSG cells.

Cell Reselection between allowed CSG cells is based on normal cell reselection procedure.

10.5.1.2 RRC_CONNECTED

While the UE is in RRC_CONNECTED state, the UE performs normal measurement and mobility procedures based on configuration provided by the network.

The UE is not required to support manual selection of CSG IDs while in RRC_CONNECTED state.

10.5.2 Outbound mobility from CSG cells

10.5.2.1 RRC_IDLE

For a UE leaving a CSG cell in idle mode normal cell reselection based on configuration from the BCCH of the CSG cell applies.

10.5.2.2 RRC_CONNECTED

For a UE leaving a CSG cell in active mode normal network controlled mobility applies.

10.6 Measurement Model

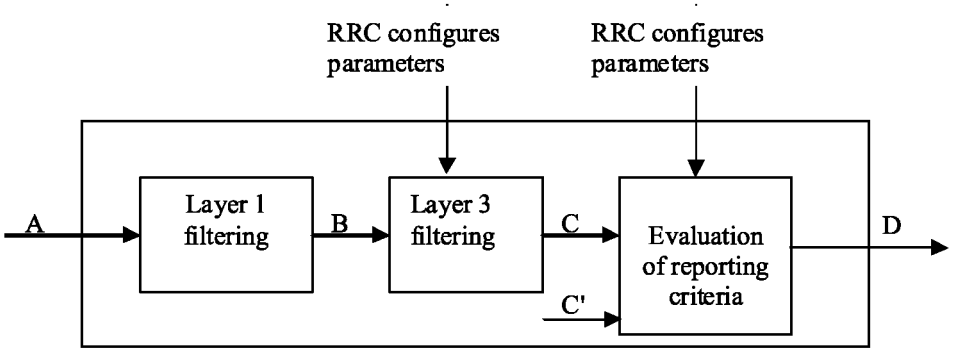


Figure 10.6-1: Measurement model

- **A:** measurements (samples) internal to the physical layer.
- **Layer 1 filtering:** internal layer 1 filtering of the inputs measured at point A. Exact filtering is implementation dependant. How the measurements are actually executed in the physical layer by an implementation (inputs A and Layer 1 filtering) in not constrained by the standard.
- **B:** A measurement reported by layer 1 to layer 3 after layer 1 filtering.
- **Layer 3 filtering:** Filtering performed on the measurements provided at point B. The behaviour of the Layer 3 filters are standardised and the configuration of the layer 3 filters is provided by RRC signalling. Filtering reporting period at C equals one measurement period at B.
- **C:** A measurement after processing in the layer 3 filter. The reporting rate is identical to the reporting rate at point B. This measurement is used as input for one or more evaluation of reporting criteria.
- **Evaluation of reporting criteria:** This checks whether actual measurement reporting is necessary at point D. The evaluation can be based on more than one flow of measurements at reference point C e.g. to compare between different measurements. This is illustrated by input C and C'. The UE shall evaluate the reporting criteria at least every time a new measurement result is reported at point C, C'. The reporting criteria are standardised and the configuration is provided by RRC signalling (UE measurements).
- **D:** Measurement report information (message) sent on the radio interface.

Layer 1 filtering will introduce a certain level of measurement averaging. How and when the UE exactly performs the required measurements will be implementation specific to the point that the output at B fulfils the performance requirements set in [21]. Layer 3 filtering and parameters used is specified in [16] and does not introduce any delay in the sample availability between B and C. Measurement at point C, C' is the input used in the event evaluation.

11 Scheduling and Rate Control

In order to utilise the SCH resources efficiently, a scheduling function is used in MAC. In this subclause, an overview of the scheduler is given in terms of scheduler operation, signalling of scheduler decisions, and measurements to support scheduler operation.

11.1 Basic Scheduler Operation

MAC in eNB includes dynamic resource schedulers that allocate physical layer resources for the DL-SCH and UL-SCH transport channels. Different schedulers operate for the DL-SCH and UL-SCH.

The scheduler should take account of the traffic volume and the QoS requirements of each UE and associated radio bearers, when sharing resources between UEs. Only 'per UE' grants are used to grant the right to transmit on the UL-SCH (i.e. there are no 'per UE per RB' grants).

Schedulers may assign resources taking account the radio conditions at the UE identified through measurements made at the eNB and/or reported by the UE.

Radio resource allocations can be valid for one or multiple TTIs.

Resource assignment consists of physical resource blocks (PRB) and MCS. Allocations for time periods longer than one TTI might also require additional information (allocation time, allocation repetition factor…).

11.1.1 Downlink Scheduling

In the downlink, E-UTRAN can dynamically allocate resources (PRBs and MCS) to UEs at each TTI via the C-RNTI on PDCCH(s). A UE always monitors the PDCCH(s) in order to find possible allocation when its downlink reception is enabled (activity governed by DRX when configured).

In addition, E-UTRAN can allocate semi-persistent downlink resources for the first HARQ transmissions to UEs:

- RRC defines the periodicity of the semi-persistent downlink grant;
- PDCCH indicates whether the downlink grant is a semi-persistent one i.e. whether it can be implicitly reused in the following TTIs according to the periodicity defined by RRC.

When required, retransmissions are explicitly signalled via the PDCCH(s). In the sub-frames where the UE has semi-persistent downlink resource, if the UE cannot find its C-RNTI on the PDCCH(s), a downlink transmission according to the semi-persistent allocation that the UE has been assigned in the TTI is assumed. Otherwise, in the sub-frames where the UE has semi-persistent downlink resource, if the UE finds its C-RNTI on the PDCCH(s), the PDCCH allocation overrides the semi-persistent allocation for that TTI and the UE does not decode the semi-persistent resources.

11.1.2 Uplink Scheduling

In the uplink, E-UTRAN can dynamically allocate resources (PRBs and MCS) to UEs at each TTI via the C-RNTI on PDCCH(s). A UE always monitors the PDCCH(s) in order to find possible allocation for uplink transmission when its downlink reception is enabled (activity governed by DRX when configured).

In addition, E-UTRAN can allocate a semi-persistent uplink resource for the first HARQ transmissions and potentially retransmissions to UEs:

- RRC defines the periodicity of the semi-persistent uplink grant;
- PDCCH indicates whether the uplink grant is a semi-persistent one i.e. whether it can be implicitly reused in the following TTIs according to the periodicity defined by RRC.

In the sub-frames where the UE has semi-persistent uplink resource, if the UE cannot find its C-RNTI on the PDCCH(s), an uplink transmission according to the semi-persistent allocation that the UE has been assigned in the TTI can be made. The network performs decoding of the pre-defined PRBs according to the pre-defined MCS. Otherwise, in the sub-frames where the UE has semi-persistent uplink resource, if the UE finds its C-RNTI on the PDCCH(s), the PDCCH allocation overrides the persistent allocation for that TTI and the UE"s transmission follows the PDCCH

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allocation, not the semi-persistent allocation. Retransmissions are either implicitly allocated in which case the UE uses the semi-persistent uplink allocation, or explicitly allocated via PDCCH(s) in which case the UE does not follow the semi-persistent allocation.

NOTE: there is no blind decoding in uplink and when the UE does not have enough data to fill the allocated resource, padding is used.

11.2 Void

11.3 Measurements to Support Scheduler Operation

Measurement reports are required to enable the scheduler to operate in both uplink and downlink. These include transport volume and measurements of a UEs radio environment.

Uplink buffer status reports (BSR) are needed to provide support for QoS-aware packet scheduling. In E-UTRAN uplink buffer status reports refer to the data that is buffered in for a group of radio bearer (RBG) in the UE. Four RBGs and two formats are used for reporting in uplink:

- A short format for which only one BSR (of one RBG) is reported;
- A long format for which all four BSRs (of all four RBGs) are reported.

Uplink buffer status reports are transmitted using MAC signalling.

11.4 Rate Control of GBR and UE-AMBR

11.4.1 Downlink

The eNB guarantees the downlink GBR associated with a GBR bearer and enforces the downlink AMBR associated with a group of Non-GBR bearers.

11.4.2 Uplink

The UE has an uplink rate control function which manages the sharing of uplink resources between radio bearers. RRC controls the uplink rate control function by giving each bearer a priority and a prioritised bit rate (PBR). The values signalled may not be related to the ones signalled via S1 to the eNB.

The uplink rate control function ensures that the UE serves its radio bearer(s) in the following sequence:

1. All the radio bearer(s) in decreasing priority order up to their PBR;
2. All the radio bearer(s) in decreasing priority order for the remaining resources assigned by the grant.

NOTE1: In case the PBRs are all set to zero, the first step is skipped and the radio bearer(s) are served in strict priority order: the UE maximises the transmission of higher priority data.

NOTE2: By limiting the total grant to the UE, the eNB can ensure that the UE-AMBR is not exceeded.

If more than one radio bearer has the same priority, the UE shall serve these radio bearers equally.

11.5 CQI reporting for Scheduling

The time and frequency resources used by the UE to report CQI are under the control of the eNB. CQI reporting can be either periodic or aperiodic. A UE can be configured to have both periodic and aperiodic reporting at the same time. In case both periodic and aperiodic reporting occurs in the same subframe, only the aperiodic report is transmitted in that subframe.

For efficient support of localized, distributed and MIMO transmissions, E-UTRA supports three types of CQI reporting:

- Wideband type: providing channel quality information of entire system bandwidth of the cell;
- Multi-band type: providing channel quality information of some subset(s) of system bandwidth of the cell;
- MIMO type: open loop or closed loop operation (with or without PMI feedback).

Periodic CQI reporting is defined by the following characteristics:

- When the UE is allocated PUSCH resources in a subframe where a periodic CQI report is configured to be sent, the periodic CQI report is transmitted together with uplink data on the PUSCH. Otherwise, the periodic CQI reports are sent on the PUCCH.

Aperiodic CQI reporting is defined by the following characteristics:

- The report is scheduled by the eNB via the PDCCH;
- Transmitted together with uplink data on PUSCH.

When a CQI report is transmitted together with uplink data on PUSCH, it is multiplexed with the transport block by L1 (i.e. the CQI report is not part of the uplink the transport block).

The eNB configures a set of sizes and formats of the reports. Size and format of the report depends on whether it is transmitted over PUCCH or PUSCH and whether it is a periodic or aperiodic CQI report.

12 DRX in RRC_CONNECTED

In order to enable reasonable UE battery consumption, DRX in E-UTRAN is characterised by the following:

- Per UE mechanism (as opposed to per radio bearer);
- No RRC or MAC substate to distinguish between different levels of DRX;
- Available DRX values are controlled by the network and start from non-DRX up to *x* seconds. Value *x* may be as long as the paging DRX used in ECM-IDLE;
- Measurement requirement and reporting criteria can differ according to the length of the DRX interval i.e. long DRX intervals may experience more relaxed requirements;
- Irrespective of DRX, UE may use first available RACH opportunity to send an UL measurement report;
- Immediately after sending a measurement report, the UE may change its DRX. This mechanism would be pre-configured by the eNB;
- HARQ operation related to data transmission is independent of DRX operation and the UE wakes up to read the PDCCH for possible retransmissions and/or ACK/NAK signalling regardless of DRX In the downlink, a timer is used to limit the time the UE stays awake awaiting for a retransmission;
- When DRX is configured, the UE may be further configured with an "on-duration" timer during which time the UE monitors the PDCCHs for possible allocations;
- When DRX is configured, periodic CQI reports can only be sent by the UE during the 'active-time'. RRC can further restrict periodic CQI reports so that they are only sent during the on-duration;
- A timer in the UE is used to detect need for obtaining timing advance.

The following definitions apply to DRX in E-UTRAN:

- **on-duration**: duration in downlink subframes that the UE waits for, after waking up from DRX, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;
- **inactivity-timer**: duration in downlink subframes that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it re-enters DRX. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions).

- **active-time**: total duration that the UE is awake. This includes the 'on-duration' of the DRX cycle, the time UE is performing continuous reception while the inactivity timer has not expired and the time UE is performing continuous reception while waiting for a DL retransmission after one HARQ RTT. Based on the above the minimum active time is of length equal to on-duration, and the maximum is undefined (infinite);

Of the above parameters the on-duration and inactivity-timer are of fixed lengths, while the active-time is of varying lengths based on scheduling decision and UE decoding success. Only on-duration and inactivity-timer duration are signalled to the UE by the eNB:

- There is only one DRX configuration applied in the UE at any time;
- UE shall apply an on-duration on wake-up from DRX sleep;

NOTE: this is also applicable for the case where the UE has only one service (e.g. Real Time) that is being handled through the allocation of predefined resources; this allows for other signalling such as RRC to be sent during the remaining portion of the active time.

- New transmissions can only take place during the active-time (so that when the UE is waiting for one retransmission only, it does not have to be 'awake' during the RTT).
- If PDCCH has not been successfully decoded during the on-duration, the UE shall follow the DRX configuration (i.e. the UE can enter DRX sleep if allowed by the DRX configuration):
  - This applies also for the sub-frames where the UE has been allocated predefined resources.
- If it successfully decodes a PDCCH for a first transmission, the UE shall stay awake and start the inactivity timer (even if a PDCCH is successfully decoded in the sub-frames where the UE has also been allocated predefined resources) until a MAC control message tells the UE to re-enter DRX, or until the inactivity timer expires. In both cases, the DRX cycle that the UE follows after re-entering DRX is given by the following rules:
  - If a short DRX cycle is configured; the UE first follows the short DRX cycle and after a longer period of inactivity the UE follows the long DRX cycle;
  - Else the UE follows the long DRX cycle directly.

NOTE: When DRX is configured, the network should detect whether UE remains in EUTRAN coverage by requesting UE to send periodic signals to the network.

13 QoS

An EPS bearer/E-RAB is the level of granularity for bearer level QoS control in the EPC/E-UTRAN. That is, SDFs mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g. scheduling policy, queue management policy, rate shaping policy, RLC configuration, etc.) [17].

One EPS bearer/E-RAB is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN. That bearer is referred to as the *default* bearer. Any additional EPS bearer/E-RAB that is established to the same PDN is referred to as a *dedicated* bearer. The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data. The decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

An EPS bearer/E-RAB is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer/E-RAB are permanently allocated (e.g. by an admission control function in the eNodeB) at bearer establishment/modification. Otherwise, an EPS bearer/E-RAB is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or a Non-GBR bearer while a default bearer shall be a Non-GBR bearer.

13.1 Bearer service architecture

The EPS bearer service layered architecture is depicted in Figure 13.1-1 below, where:

- An UL TFT in the UE binds an SDF to an EPS bearer in the uplink direction. Multiple SDFs can be multiplexed onto the same EPS bearer by including multiple uplink packet filters in the UL TFT.
- A DL TFT in the PDN GW binds an SDF to an EPS bearer in the downlink direction. Multiple SDFs can be multiplexed onto the same EPS bearer by including multiple downlink packet filters in the DL TFT.
- An E-RAB transports the packets of an EPS bearer between the UE and the EPC. When an E-RAB exists, there is a one-to-one mapping between this E-RAB and an EPS bearer.
- A data radio bearer transports the packets of an EPS bearer between a UE and an eNB. When a data radio bearer exists, there is a one-to-one mapping between this data radio bearer and the EPS bearer/E-RAB.
- An S1 bearer transports the packets of an E-RAB between an eNodeB and a Serving GW.
- An S5/S8 bearer transports the packets of an EPS bearer between a Serving GW and a PDN GW.
- A UE stores a mapping between an uplink packet filter and a data radio bearer to create the binding between an SDF and a data radio bearer in the uplink.
- A PDN GW stores a mapping between a downlink packet filter and an S5/S8a bearer to create the binding between an SDF and an S5/S8a bearer in the downlink.
- An eNB stores a one-to-one mapping between a data radio bearer and an S1 bearer to create the binding between a data radio bearer and an S1 bearer in both the uplink and downlink.
- A Serving GW stores a one-to-one mapping between an S1 bearer and an S5/S8a bearer to create the binding between an S1 bearer and an S5/S8a bearer in both the uplink and downlink.

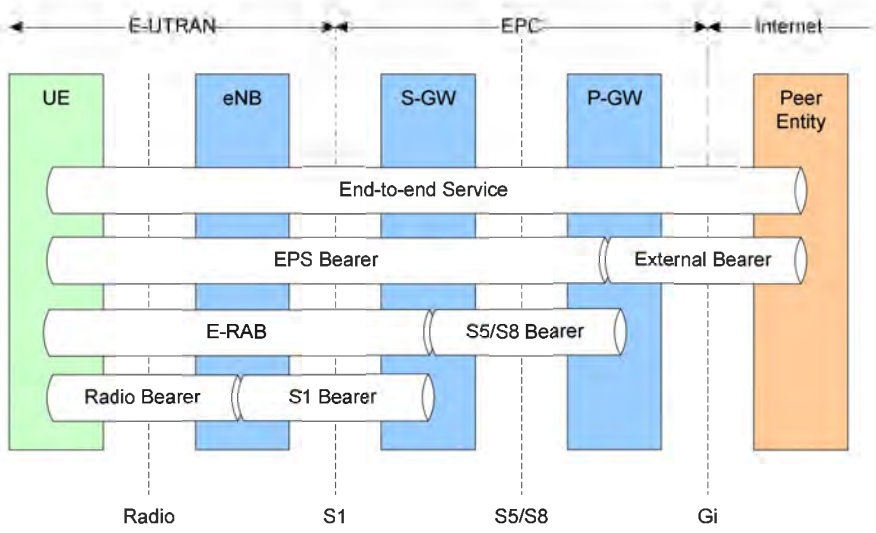


Figure 13.1-1: EPS Bearer Service Architecture

13.2 QoS parameters

The bearer level (i.e. per bearer or per bearer aggregate) QoS parameters are QCI, ARP, GBR, and AMBR [17]. Each EPS bearer/E-RAB (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- QoS Class Identifier (QCI): scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the eNodeB. A one-to-one mapping of standardized QCI values to standardized characteristics is captured in [17].
- Allocation and Retention Priority (ARP): the primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations. In

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addition, the ARP can be used by the eNodeB to decide which bearer(s) to drop during exceptional resource limitations (e.g. at handover).

Each GBR bearer is additionally associated with the following bearer level QoS parameter:

- Guaranteed Bit Rate (GBR): the bit rate that can be expected to be provided by a GBR bearer,

Each APN access, by a UE, is associated with the following QoS parameter:

- per APN Aggregate Maximum Bit Rate (APN-AMBR).

Each UE in state EMM-REGISTERED is associated with the following bearer aggregate level QoS parameter:

- per UE Aggregate Maximum Bit Rate (UE-AMBR).

The definitions of APN AMBR and UE-AMBR are captured in [17].

The GBR denotes bit rate of traffic per bearer while UE-AMBR/APN-AMBR denote bit rate of traffic per group of bearers. Each of those QoS parameters has an uplink and a downlink component.

14 Security

14.1 Overview and Principles

The following principles apply to E-UTRAN security:

- The keys used for NAS and AS protection shall be dependent on the algorithm with which they are used.
- The eNB keys are cryptographically separated from the EPC keys used for NAS protection (making it impossible to use the eNB key to figure out an EPC key).
- The AS (RRC and UP) and NAS keys are derived in the EPC/UE from key material that was generated by a NAS (EPC/UE) level AKA procedure (K_{ASME}) and identified with a key identifier (KSI_{ASME}).
- The eNB key (K_{eNB}) is sent from the EPC to the eNB when the UE is entering ECM-CONNECTED state (i.e. during RRC connection or S1 context setup).
- Separate AS and NAS level security mode command procedures are used. AS level security mode command procedure configures AS security (RRC and user plane) and NAS level security mode command procedure configures NAS security. Both integrity protection and ciphering for RRC are activated within the same AS SMC procedure, but not necessarily within the same message. User plane ciphering is activated at the same time as RRC ciphering.
- Keys stored inside eNBs shall never leave a secure environment within the eNB (except when done in accordance with this or other 3GPP specifications), and user plane data ciphering/deciphering shall take place inside the secure environment where the related keys are stored.
- Key material for the eNB keys is sent between the eNBs during ECM-CONNECTED intra-E-UTRAN mobility.
- A sequence number (COUNT) is used as input to the ciphering and integrity protection. A given sequence number must only be used once for a given eNB key (except for identical re-transmission) on the same radio bearer in the same direction. The same sequence number can be used for both ciphering and integrity protection.
- A hyper frame number (HFN) (i.e. an overflow counter mechanism) is used in the eNB and UE in order to limit the actual number of sequence number bits that is needed to be sent over the radio. The HFN needs to be synchronized between the UE and eNB.
- If corruption of keys is detected, UE has to restart radio level attachment procedure (e.g. similar radio level procedure to idle-to-connected mode transition or initial attachment).
- No integrity protection initialisation number (FRESH).

- Since SIM access is not granted in E-UTRAN [24], idle mode UE not equipped with USIM shall not attempt to reselect to E-UTRAN. To prevent handover to E-UTRAN, UE not equipped with USIM shall not indicate E-UTRA support in UE capability signalling in other RATs.

A simplified key derivation is depicted on Figure 14.1-1 below, where:

- **K_{NASint}** is a key, which shall only be used for the protection of NAS traffic with a particular integrity algorithm This key is derived by UE and MME from K_{ASME}, as well as an identifier for the integrity algorithm.
- **K_{NASenc}** is a key, which shall only be used for the protection of NAS traffic with a particular encryption algorithm. This key is derived by UE and MME from K_{ASME}, as well as an identifier for the encryption algorithm.
- **K_{eNB}** is a key derived by UE and MME from K_{ASME}. K_{eNB} may also be derived by the target eNB from NH at handover. K_{eNB} shall be used for the derivation of K_{RRCint}, K_{RRCenc} and K_{UPenc}, and for the derivation of K_{eNB*} upon handover.
- **K_{eNB*}** is a key derived by UE and source eNB from either K_{eNB} or from a fresh NH. K_{eNB*} shall be used by UE and target eNB as a new K_{eNB} for RRC and UP traffic.
- **K_{UPenc}** is a key, which shall only be used for the protection of UP traffic with a particular encryption algorithm. This key is derived by UE and eNB from K_{eNB}, as well as an identifier for the encryption algorithm.
- **K_{RRCint}** is a key, which shall only be used for the protection of RRC traffic with a particular integrity algorithm. K_{RRCint} is derived by UE and eNB from K_{eNB}, as well as an identifier for the integrity algorithm.
- **K_{RRCenc}** is a key, which shall only be used for the protection of RRC traffic with a particular encryption algorithm. K_{RRCenc} is derived by UE and eNB from K_{eNB} as well as an identifier for the encryption algorithm.
- Next Hop (**NH**) is used by UE and eNB in the derivation of K_{eNB*} for the provision of "forward security" [22]. NH is derived by UE and MME from K_{ASME} and K_{eNB} when the security context is established, or from K_{ASME} and previous NH, otherwise.
- Next Hop Chaining Count (**NCC**) is a counter related to NH (i.e. the amount of Key chaining that has been performed) which allow the UE to be synchronised with the eNB and to determine whether the next **K_{eNB*}** needs to be based on the current K_{eNB} or a fresh NH.

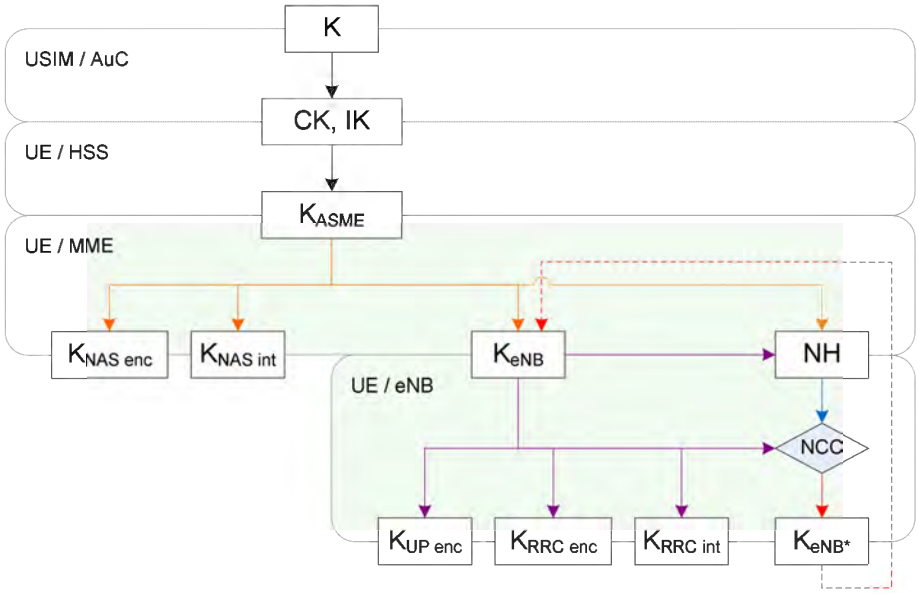


Figure 14.1-1: Key Derivation

The MME invokes the AKA procedures by requesting authentication vectors to the HE (Home environment) if no unused EPS authentication vectors have been stored. The HE sends an authentication response back to the MME that contains a fresh authentication vector, including a base-key named K_{ASME}. Thus, as a result of an AKA run, the EPC and the UE share K_{ASME}. From K_{ASME}, the NAS keys, (and indirectly) K_{eNB} keys and NH are derived. The K_{ASME} is never

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transported to an entity outside of the EPC, but K_{eNB} and NH are transported to the eNB from the EPC when the UE transitions to ECM-CONNECTED. From the K_{eNB}, the eNB and UE can derive the UP and RRC keys.

RRC and UP keys are refreshed at handover. K_{eNB*} is derived by UE and source eNB from target PCI, target frequency and K_{eNB} (this is referred to as a *horizontal* key derivation and is indicated to UE with an NCC that does not increase) or from target PCI, target frequency and NH (this is referred to as a *vertical* key derivation and is indicated to UE with an NCC increase). K_{eNB*} is then used as new K_{eNB} for RRC and UP traffic at the target. When the UE goes into ECM-IDLE all keys are deleted from the eNB.

COUNT reusing avoidance for the same radio bearer identity in RRC_CONNECTED mode without K_{eNB} change is left to eNB implementation e.g. by using intra-cell handover, smart management of radio bearer identities or triggering a transition to RRC_IDLE.

In case of HFN de-synchronisation in RRC_CONNECTED mode between the UE and eNB, the UE is pushed to IDLE.

14.2 Security termination points

The table below describes the security termination points.

Table 14.2-1 Security Termination Points

	Ciphering	Integrity Protection
NAS Signalling	Required and terminated in MME	Required and terminated in MME
U-Plane Data	Required and terminated in eNB	Not Required (NOTE 1)
RRC Signalling (AS)	Required and terminated in eNB	Required and terminated in eNB
MAC Signalling (AS)	Not required	Not required
NOTE 1: Integrity protection for U-Plane is not required and thus it is not supported between UE and Serving Gateway or for the transport of user plane data between eNB and Serving Gateway on S1 interface.		

14.3 State Transitions and Mobility

14.3.1 RRC_IDLE to RRC_CONNECTED

As a general principle, on RRC_IDLE to RRC_CONNECTED transitions, RRC protection keys and UP protection keys shall be generated while keys for NAS protection as well as higher layer keys are assumed to be already available in the MME. These higher layer keys may have been established in the MME as a result of an AKA run, or as a result of a transfer from another MME during handover or idle mode mobility [22].

14.3.2 RRC_CONNECTED to RRC_IDLE

On RRC_CONNECTED to RRC_IDLE transitions, eNBs shall delete the keys they store such that state for idle mode UEs only has to be maintained in MME. It is also assumed that eNB does no longer store state information about the corresponding UE and deletes the current keys from its memory. In particular, on connected to idle transitions:

- The eNB and UE deletes NH, K_{eNB} , K_{RRCenc} , K_{RRCint} and K_{UPenc} and related NCC.
- MME and UE keeps K_{ASME}, K_{NASint} and K_{NASenc} stored.

14.3.3 Intra E-UTRAN Mobility

The key hierarchy does not allow, as is, explicit RRC and UP key updates, but RRC and UP keys are derived based on the algorithm identifiers and K_{eNB} which results with new RRC and UP keys at every handover:

- Source eNB and UE independently create K_{eNB*} with the input parameters as described in 3GPP TS 33.401 [22];