REV-090004

LTE-Advanced
Radio Layer 2 and RRC aspects

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3GPP TSG-RAN WG2

Outline

E-UTRA overview

- LTE Advanced features
- E-UTRAN architecture
- User plane protocol stack
- Control plane protocol stack

User plane

- Reliable transport
- U-plane data flow
- Scheduling
- DRX
- Security

Control plane

- System information
- Connection control
- RRC state model
- IDLE mode mobility
- CONNECTED mode mobility
- Radio Link Failure handling
- Random Access
- Priority access

Performance

- U-plane latency
- C-plane latency
- HO interruption

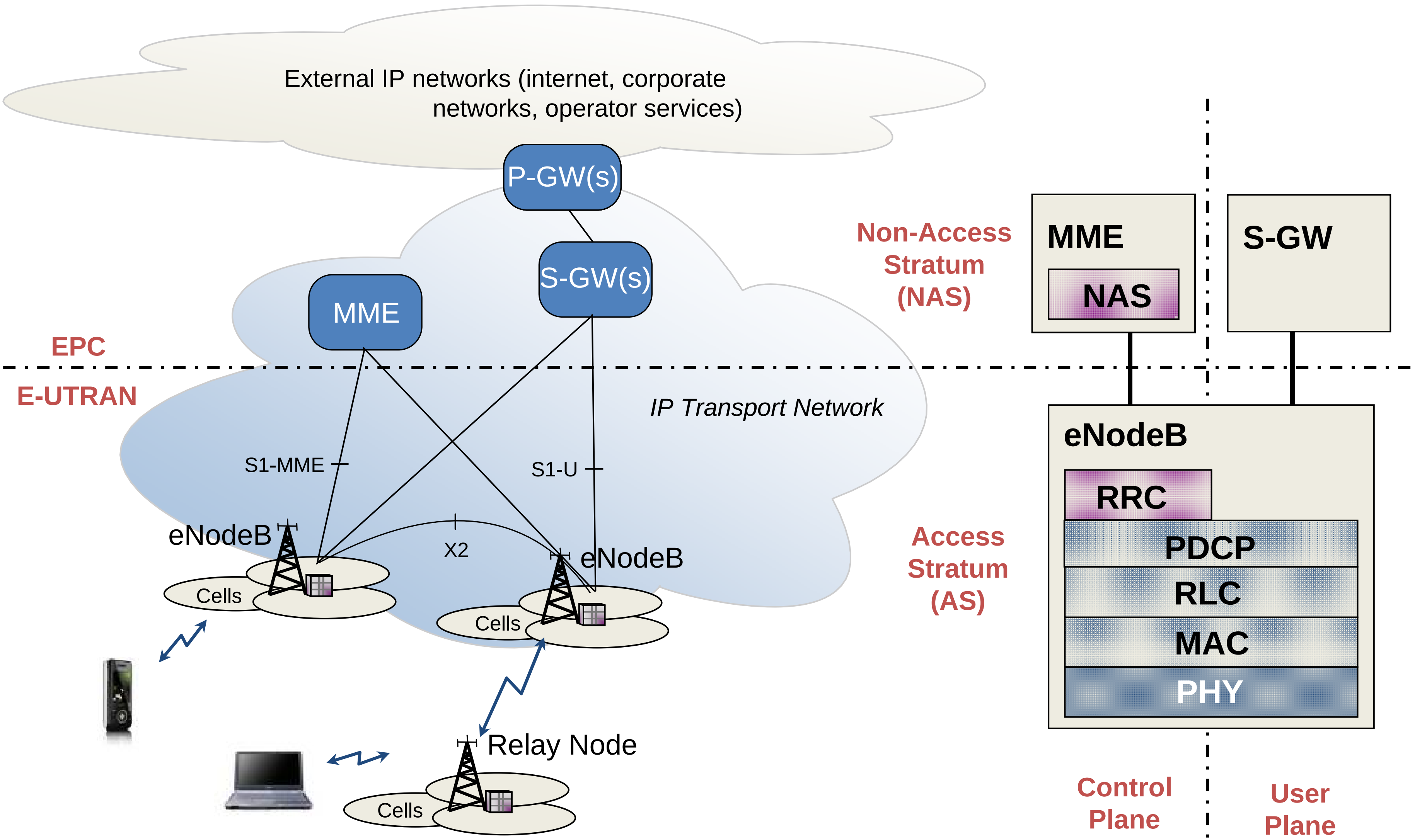
LTE Advanced features

- LTE Advanced supports:
  - Reliable, high rate, high capacity and low latency data transfer
    - suitable for a wide range of services
  - Mobility
    - seamless and lossless (using packet forwarding)
    - optimized for low mobile speed from 0 to 15 km/h
    - higher mobile speed between 15 and 120 km/h also supported with high performance
    - mobility across the cellular network can be maintained at speeds from 120 km/h to 350 km/h (or even up to 500 km/h depending on the frequency band)
  - Relays
    - to improve e.g. the coverage of high data rates, temporary network deployment, cell-edge throughput and/or to provide coverage in new areas
    - relay node wirelessly connected to donor cell of donor eNB
  - Carrier and spectrum aggregation
    - to support wider transmission bandwidths up to 100MHz and spectrum aggregation
    - aggregation of both contiguous and non-contiguous component carriers is supported
  - Coordinated Multi-Point transmission and reception
    - to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput

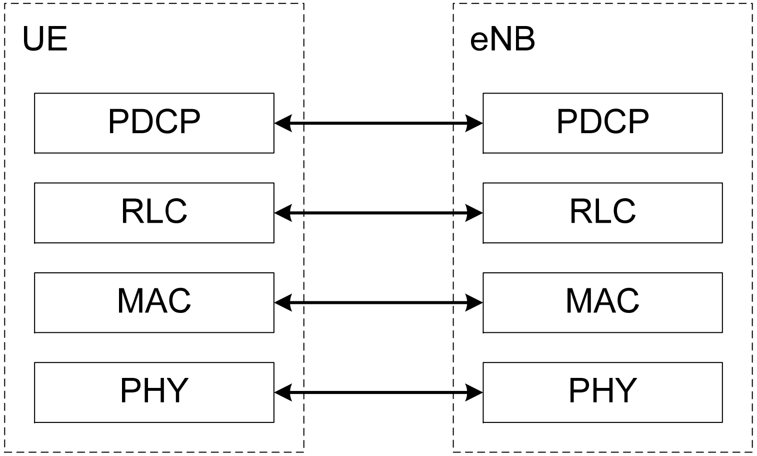
LTE Advanced features (cont'd)

- LTE Advanced further supports:
  - Emergency Calls
    - Provisioning of emergency call service to user equipment in both normal service mode (authenticated) and limited service mode (unauthenticated)
  - Positioning
    - UE location determination through user plane and control plane based solutions; e.g., A-GNSS, OTDOA, cell level granularity location reporting
  - Public warning systems (PWS)
    - Provisioning of timely and accurate alerts, warnings and critical information regarding disasters and other emergencies through Earthquake and Tsunami Warning System (ETWS) and Commercial Mobile Alert System (CMAS)
  - Home eNB (HeNB)
    - Provisioning of LTE service through customer-premises equipment using operator's licenced spectrum
  - Multimedia Broadcast/Multicast Service (MBMS)
    - Multi-cell broadcast of multimedia services through efficient Single Frequency Network (SFN) mode of operation

E-UTRAN architecture



User plane protocol stack

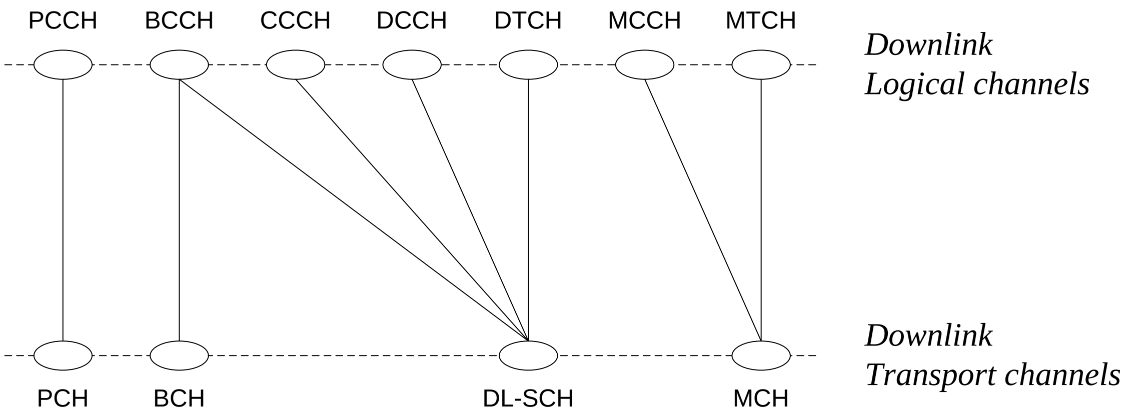


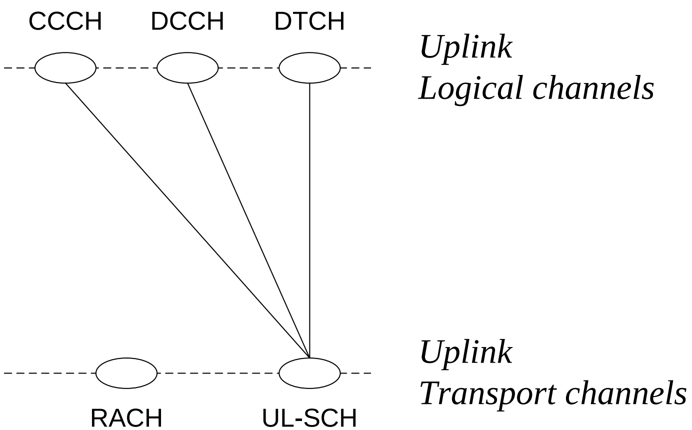
- PDCP (Packet Data Convergence Protocol) TS 36.323
  - Header compression using the RoHC protocol†;
  - In-sequence delivery and retransmission of PDCP SDUs for AM Radio Bearers at handover;
  - Duplicate detection;
  - Ciphering;
  - Integrity protection‡.
- RLC (Radio Link Control) TS 36.322
  - Transfer of upper layer PDUs supporting AM, UM and TM data transfer;
  - Error Correction through ARQ;
  - Segmentation according to the size of the TB;
  - Re-segmentation of PDUs that need to be retransmitted;
  - Concatenation of SDUs for the same radio bearer;
  - Protocol error detection and recovery;
  - In-sequence delivery
- MAC (Media Access Control) TS 36.321
  - Multiplexing/demultiplexing of RLC PDUs
  - Scheduling Information reporting;
  - Error correction through HARQ;
  - Logical Channel Prioritisation;
  - Padding;

†) for U-plane ‡) for C-plane

Channel Mapping

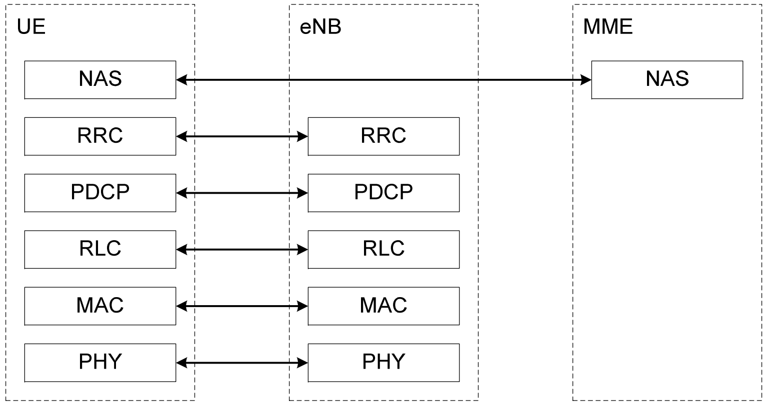
- Transport Channels:
  - PCH: Paging Ch.
  - BCH: Broadcast Ch.
  - MCH: Multicast Ch.
  - DL-SCH: Downlink Shared Ch.
  - UL-SCH: Uplink Shared Ch.
- Logical channels:
  - PCCH: Paging Control Ch.
  - BCCH: Broadcast Control Ch.
  - CCCH: Common Control Ch.
  - DCCH: Dedicated Control Ch.
  - DTCH: Dedicated Traffic Ch.
  - MCCH: Multicast Control Ch.
  - MTCH: Multicast Traffic Ch.





Control plane protocol stack

- RLC and MAC sublayers perform the same functions as for the user plane.
- PDCP sublayer performs ciphering and integrity protection.



- RRC (Radio Resource Control) protocol performs:

TS 36.331

  - Broadcast of System Information related to NAS and AS;
  - Establishment, maintenance and release of RRC connection;
  - Establishment, configuration, maintenance and release of Signalling and Data Radio Bearers (SRBs and DRBs);
  - Security functions including key management;
  - Mobility functions including, e.g.:
    - Control of UE cell selection/reselection; Paging; UE measurement configuration and reporting; Handover;
  - QoS management functions;
  - UE measurement reporting and control of the reporting;
  - Notification for ETWS, CMAS and MBMS;
  - NAS direct message transfer between UE and NAS.

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- U-plane data flow
- Scheduling
- DRX
- Security

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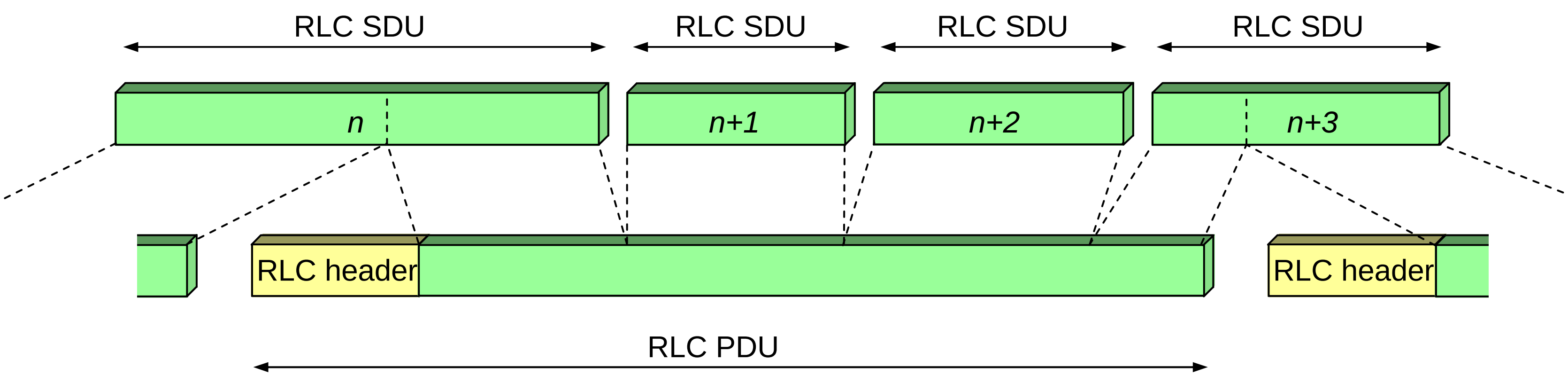
Reliable transport
Retransmission protocols

- L1 applies 24 bit CRC protection to transport blocks (MAC PDUs)
  - Erroneous transport blocks are discarded on L1
- Hybrid ARQ protocol in MAC complemented by ARQ protocol in RLC† for high reliability and radio efficiency
  - HARQ feedback sent on L1/L2 control channel
    - Single, uncoded bit (low overhead)
    - Sent for each scheduled subframe (fast)
    - Retransmissions are soft-combined with previous attempt (efficient)
  - ARQ status report sent as MAC data
    - protected by CRC and HARQ retransmissions
    - RLC Status is sent on demand (poll, timer, gap detection)
- Both HARQ and ARQ protocols terminated in the eNB
  - fast handling of residual HARQ errors
- Ensures low latency and high reliability

†) RLC AM (Acknowledged Mode) only. No retransmissions in RLC UM (Unacknowledged mode).

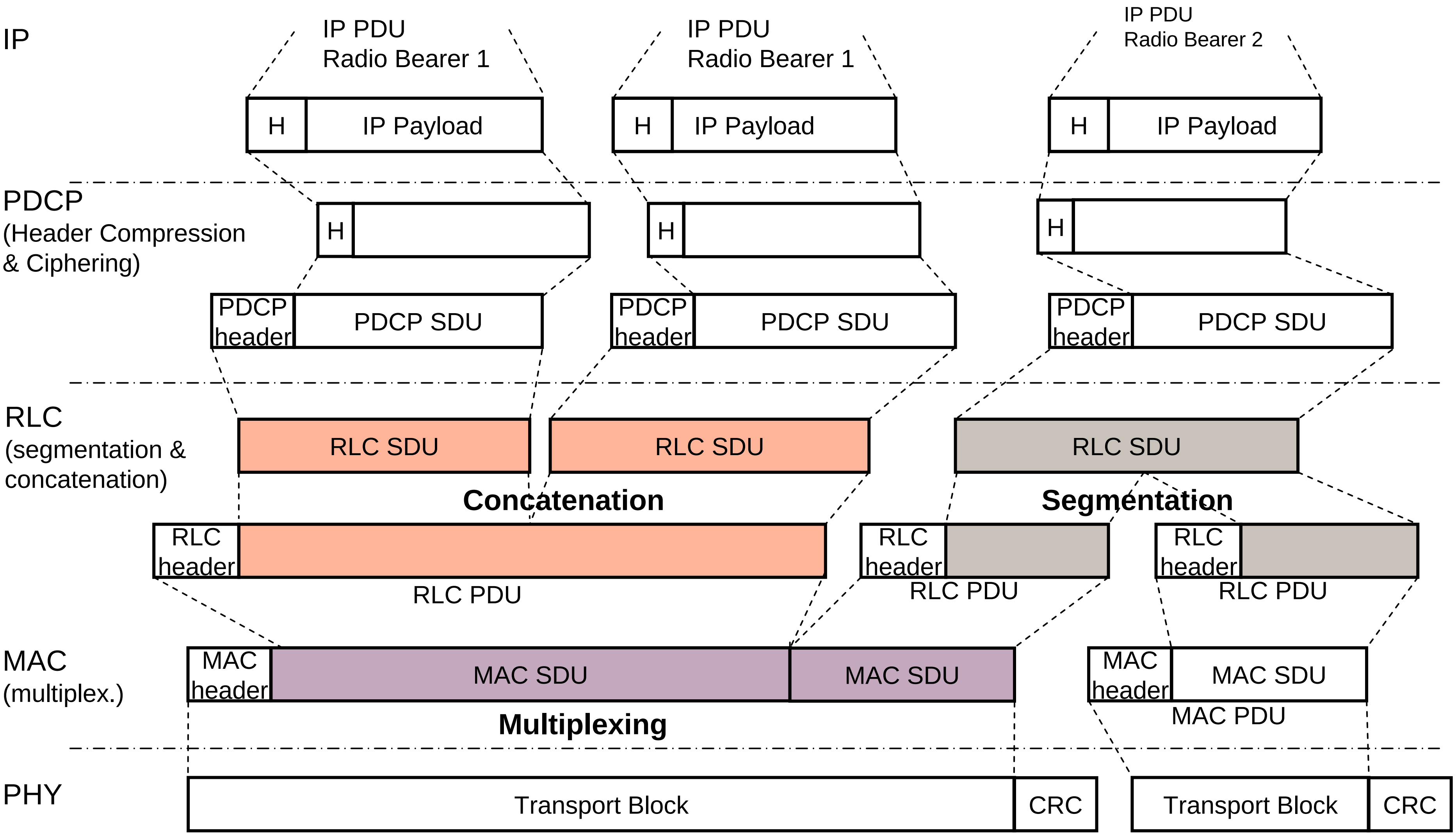
Reliable transport
Lossless and in-sequence delivery

- Lossless and in-sequence delivery of data provided by:
  - RLC retransmission (ARQ) and re-ordering functions for normal operation (based on RLC SNs)
  - PDCP forwarding, retransmission and reordering functions for handover cases (based on PDCP SNs)
    - For RLC AM data radio bearers only
    - PDCP SNs are maintained across handovers
    - Lower layers (RLC/MAC) are reset



- Duplicate detection provided by PDCP
  - Duplicates may disturb TCP performance
  - Detects and removes duplicates based on PDCP Sequence Numbers (SNs)

User Plane data flow (downlink)



Scheduling

- Scheduler residing in eNB with objective of:
  - Fulfilling of "QoS Contracts“;
  - Maximising cell throughput;
  - Providing Fairness,

  based on measurements, scheduling information and QoS parameters.

- Scheduling Information from UE, e.g.:
  - Channel Quality Indication; Buffer Status Report; Power Headroom Report; Uplink Sounding.

- QoS framework with per bearer granularity
  - Bearers associated with several QoS parameters, e.g.:
    - QoS Class Identifier (**QCI**); Guaranteed Bit Rate (**GBR**); Allocation and Retention Priority (**ARP**); Logical Channel Priority; Prioritised Bit Rate (**PBR**); Aggregate Maximum Bitrate (**AMBR**).
  - Supports wide range of services, e.g.:
    - Basic conversational service class, rich conversational service class and conversational low delay service class;
    - Also interactive high delay, interactive low delay, streaming live, streaming non-live and background.

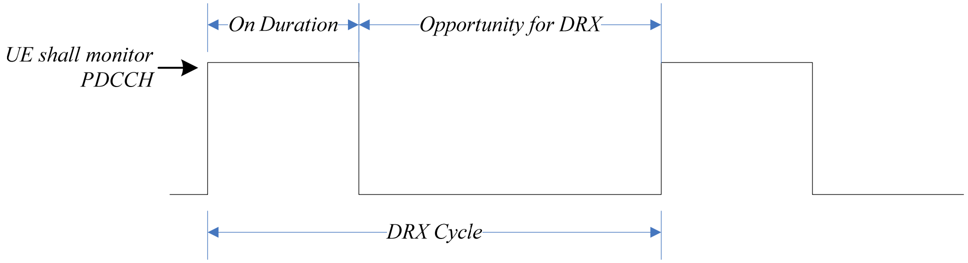
Scheduling
Dynamic & Semi-Persistent & TTI Bundling

- Scheduling decisions dynamically signaled on L1L2 control channel PDCCH
  - 1ms Transmission Time Interval (TTI) for DL-SCH and UL-SCH
  - PDCCH provides physical resource allocation, Modulation and Coding scheme, New-Data indicator, Transport Block size, Redundancy version, HARQ Process ID
  - DL: adaptive HARQ
    - All (re-)transmissions are indicated on PDCCH
    - Synchronous HARQ feedback, asynchronous retransmissions
  - UL: adaptive and non-adaptive HARQ
    - First transmission indicated on PDCCH
    - Retransmissions can be indicated on PDCCH or be derived from previous transmission parameters and HARQ feedback
    - Synchronous HARQ feedback, synchronous retransmissions

- Semi-Persistent Scheduling (SPS)
  - Reduced L1/L2 control signalling for traffic with periodic transmissions
    - UL/DL resources configured to occur at specific interval
    - Only first assignment/grant need to be signalled
    - Subsequent transmissions use the same resources as the first transmission
    - Can be deactivated with a special assignment/grant
- TTI Bundling
  - Improved coverage at lower delay
    - UE performs multiple HARQ transmission attempts in consecutive TTIs before receiving HARQ feedback
    - Less HARQ signalling reduces risk of HARQ failure

UE battery efficiency
Discontinuous Reception - DRX

- Configurable Sleep Mode for UE's receiver chain
- Periodic repetition of an "On Duration" followed by a possible period of inactivity

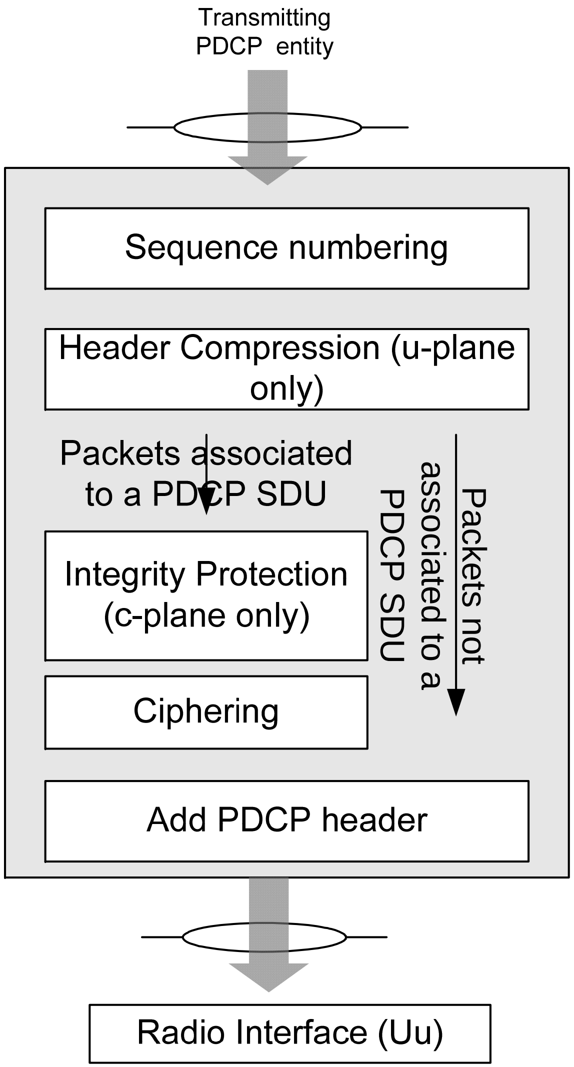


- "Active time" defines periods of mandatory activity:
  - In configured On Duration (e.g. 2 ms per 20 ms);
  - While receiving assignments or grants for new data;
    (an Inactivity Timer is (re-)started and the UE is prepared to be scheduled continuously);
  - When expecting a retransmission of a Downlink HARQ transmission (one HARQ RTT after receiving an unsuccessful DL transmission);
  - When expecting HARQ feedback for an Uplink HARQ transmission;
  - After transmitting a Scheduling Request.

- Two-level DRX scheme
  - Long DRX for very power efficient operation during periods of low activity
  - Short DRX for low latency during periods of more activity
  - autonomous transitions between states

Security
Ciphering and Integrity Protection

- AS security functions provided by PDCP controlled by RRC
  - Always activated early
  - Once started, always on
  - Based on SNOW3G and AES algorithms
  - Keys changed at handover; backward and forward security
  - Counter split in two parts for high radio efficiency:
    - Hyper Frame Number (HFN): maintained locally
    - Sequence Number (SN): signalled over the air
- Integrity protection
  - for C-plane radio bearers (Signalling Radio Bearers)
  - 32-bit Message Authentication Code (MAC-I)
  - MAC-I placed at end of PDU
- Ciphering (confidentiality protection)
  - for C-plane radio bearers (Signalling Radio Bearers)
  - for U-plane radio bearers (Data Radio Bearers)
  - PDCP Control PDUs (RoHC feedback and PDCP status reports) not ciphered



Control plane

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System Information

- System Information is provided by RRC, structured in MIB and SIBs
- MIB – transmitted in fixed location
  - Includes parameters essential to find SIB1 scheduled on DL-SCH (e.g., DL bandwidth and System Frame Number)
- SIB1 – scheduled in the frequency domain (fixed timing) on DL-SCH
  - Contains information relevant when evaluating if a UE is allowed to access a cell and defines the scheduling of other system information
- Other SIBs are multiplexed in *SystemInformationMessages*
  - Scheduled in time and frequency domains as defined by SIB1
  - SIB2
    - contains resource configuration information that is common for all UEs; needed before accessing a cell
  - SIB3, SIB4, ...
    - other system information grouped according to functionality

Connection Management

- Connection/session management is performed by:
  - the RRC protocol between the UE and E-UTRAN
  - the NAS protocol between the UE and CN
- The NAS protocol performs e.g.:
  - authentication, registration, bearer context activation/ deactivation and location registration management
- RRC messages are used e.g., to:
  - establish connection, configure the radio bearers and their corresponding attributes, and to control mobility
- The RRC protocol has two states:
  - RRC_IDLE and RRC_CONNECTED

Mobility and RRC State Models

IDLE:

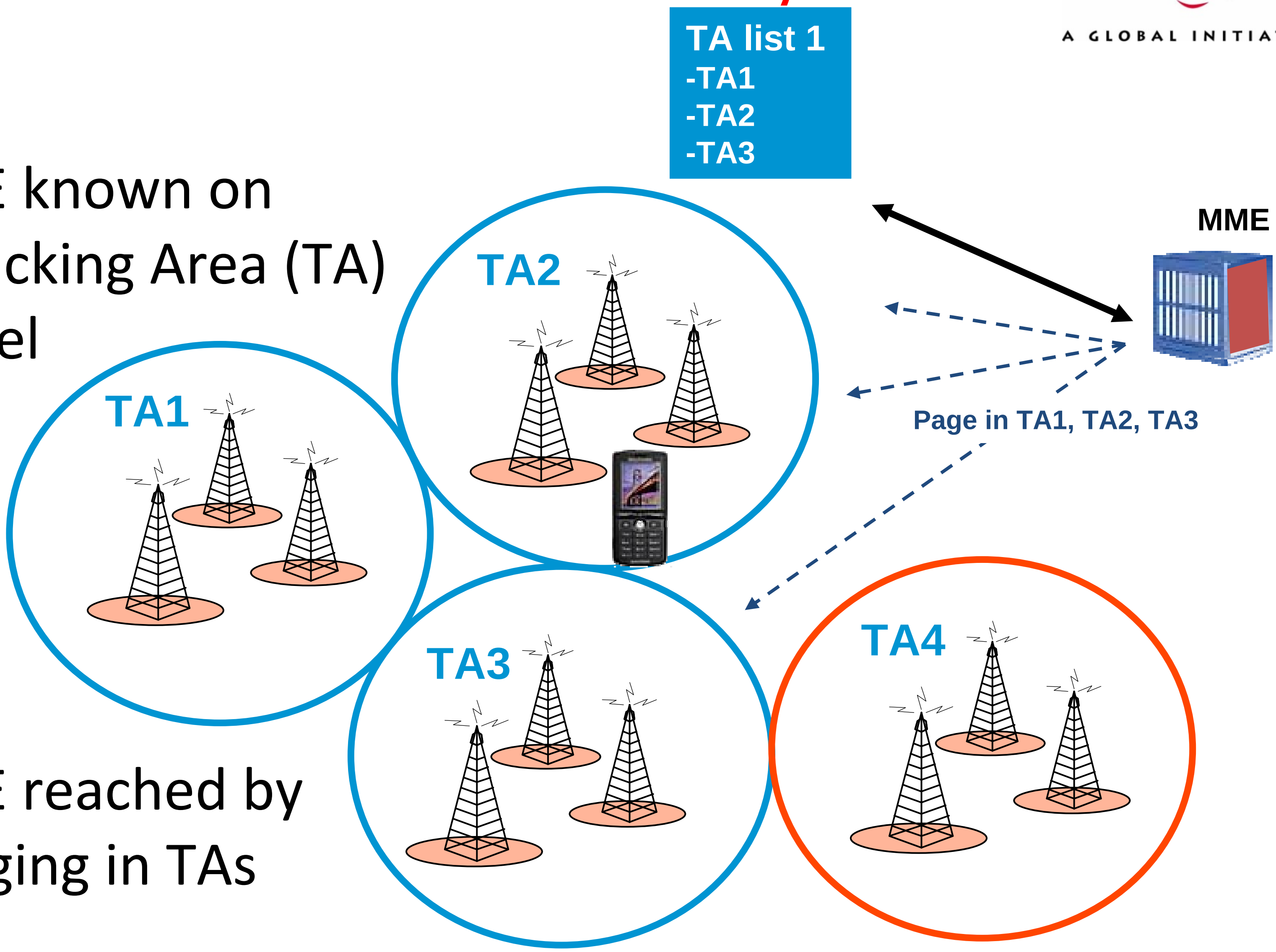
- UE known in EPC and has IP address;
- UE not known in E-UTRAN/eNB;
- UE location known on Tracking Area level;
- Unicast data transfer not possible;
- UE reached by paging in tracking areas controlled by EPC;
- UE-based cell-selection and tracking area update to EPC.

CONNECTED:

- UE known in EPC and E-UTRAN/eNB; ”context” in eNB;
- UE location known on cell level;
- Unicast data transfer possible;
- DRX supported for power saving;
- Mobility is controlled by the network.

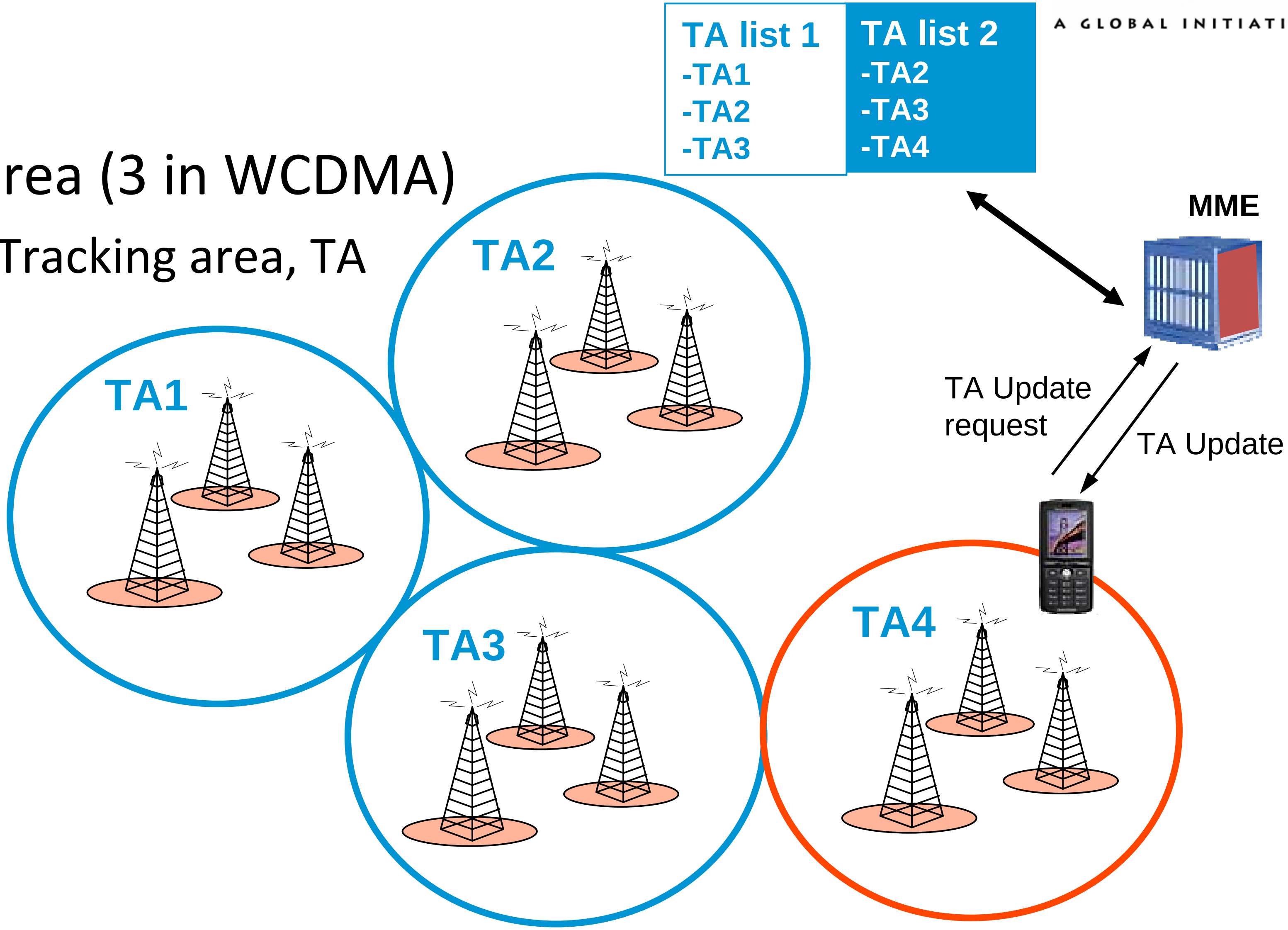
Idle Mode Molibity

- UE known on Tracking Area (TA) level
- UE reached by paging in TAs

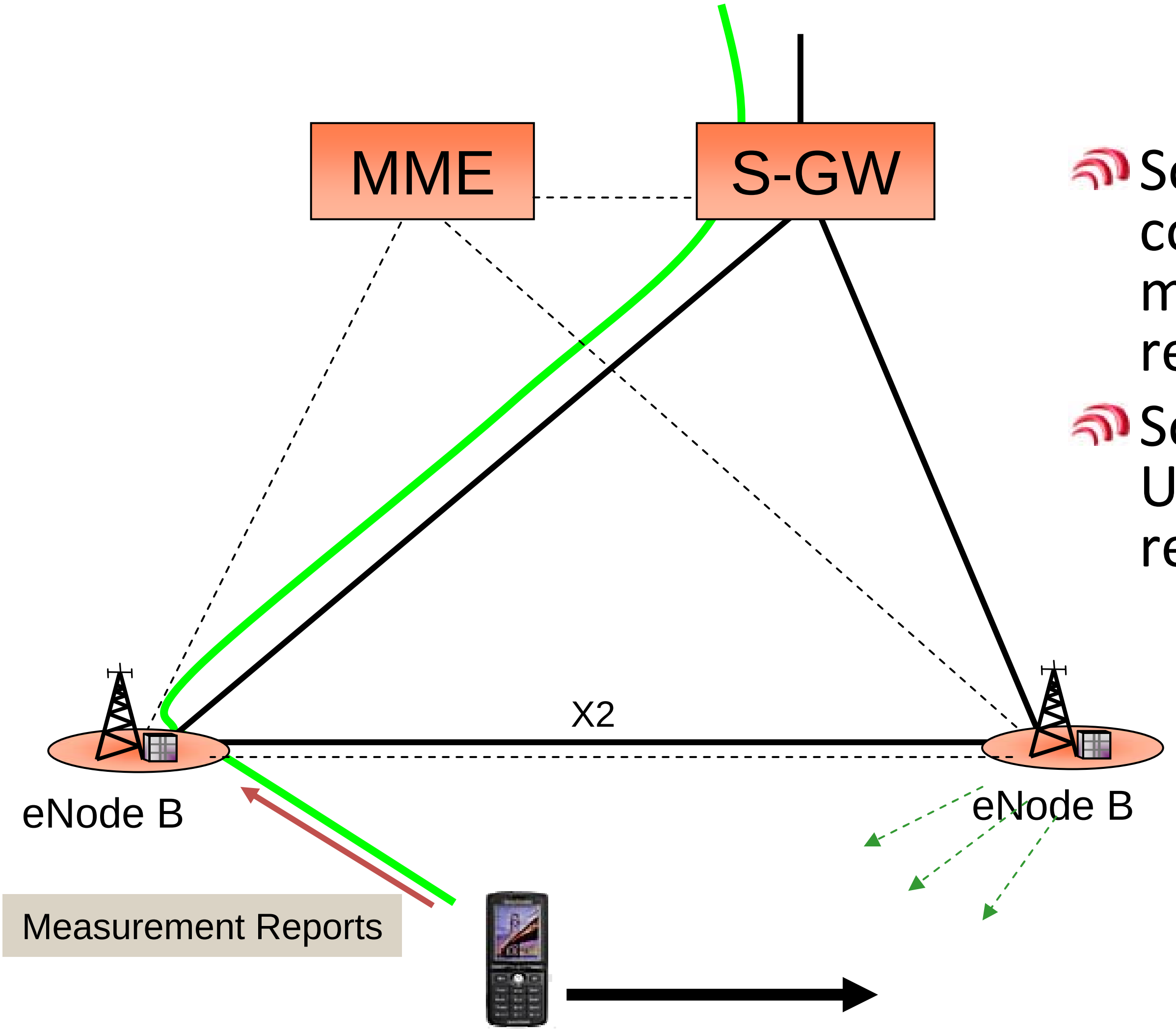


Idle Mode Mobility

- 1 area (3 in WCDMA)
  - Tracking area, TA

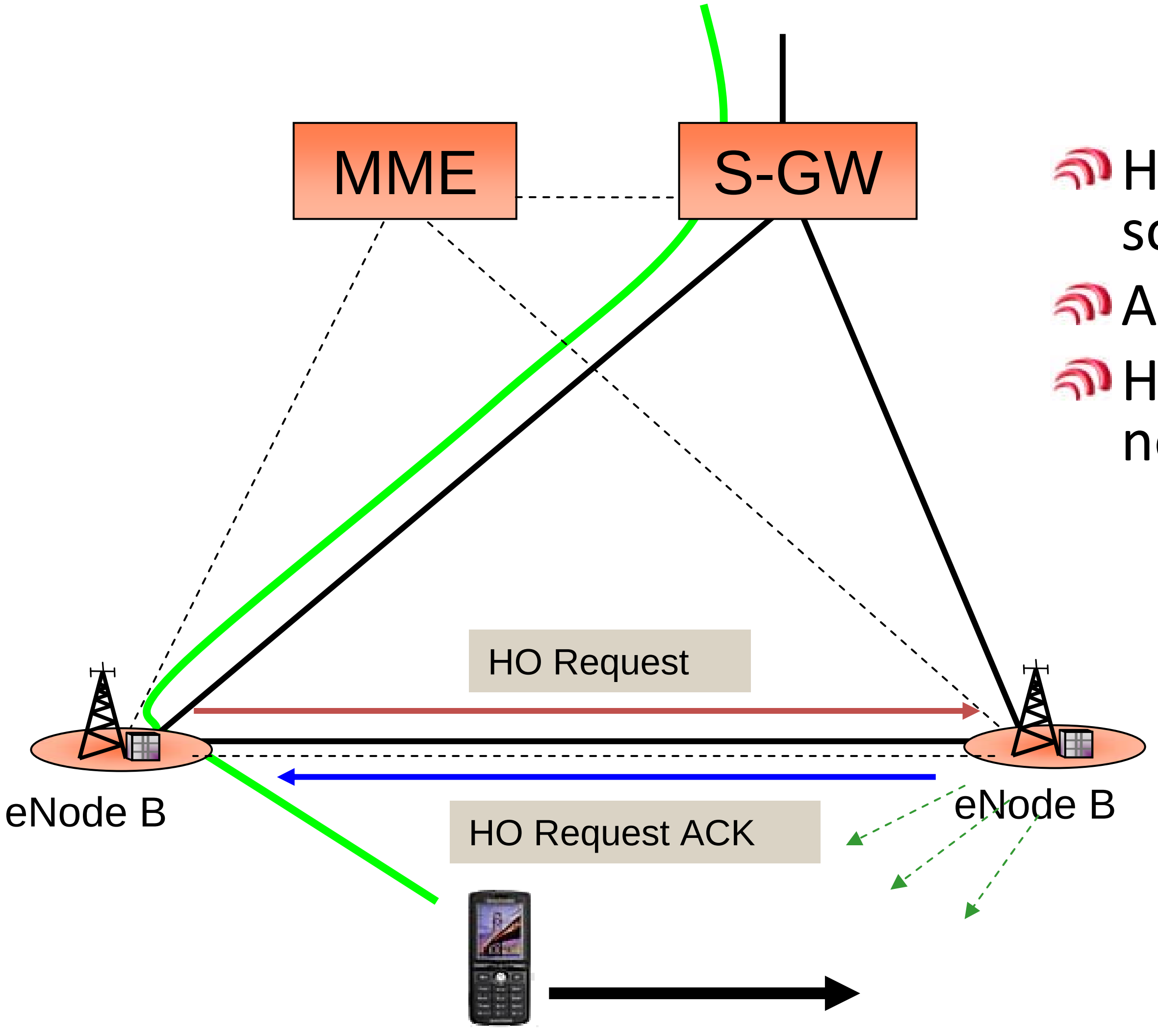


Connected State Mobility



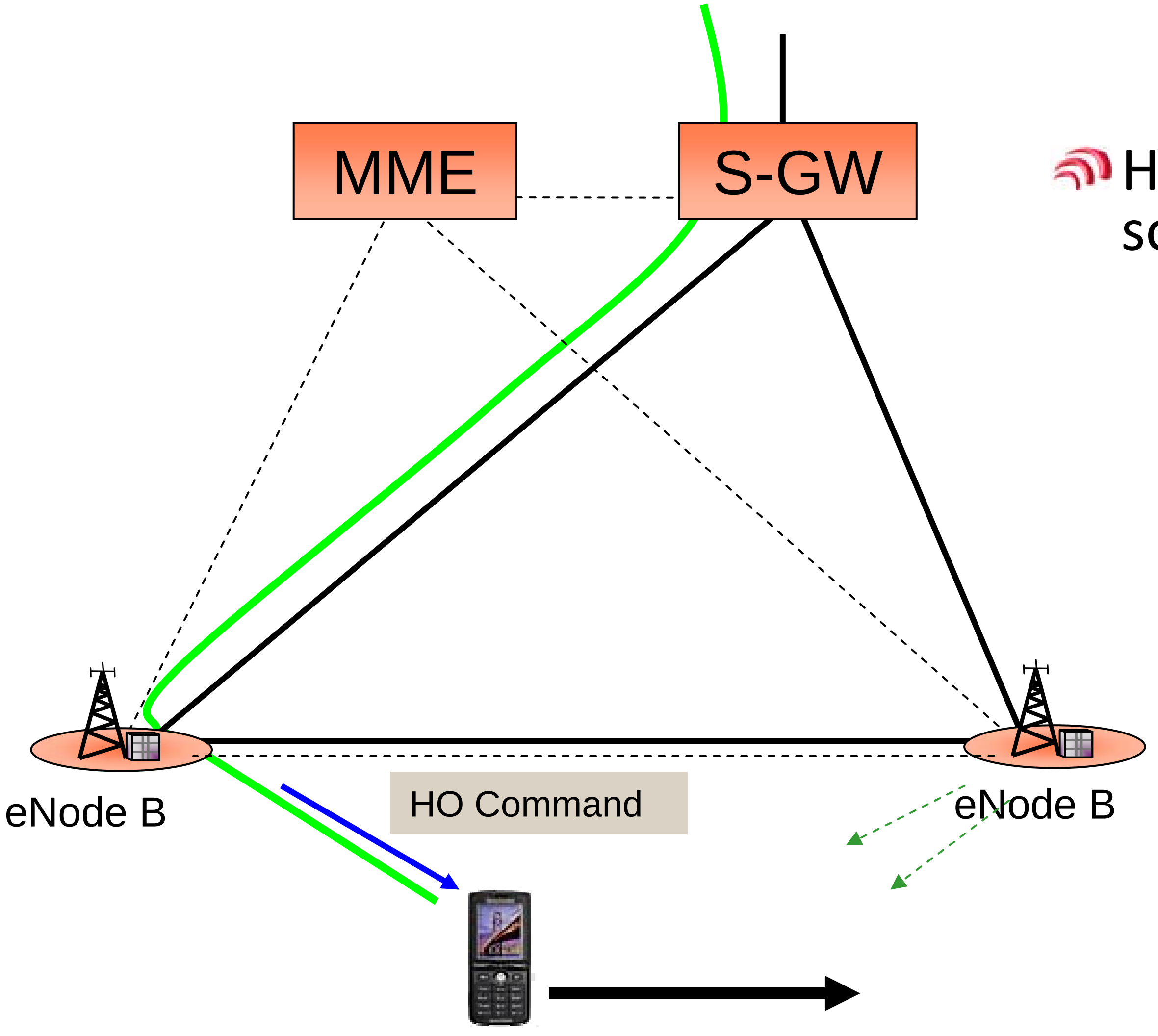
- Source eNodeB configures UE measurements and reporting
- Source eNB receives UE measurement report

Connected State Mobility



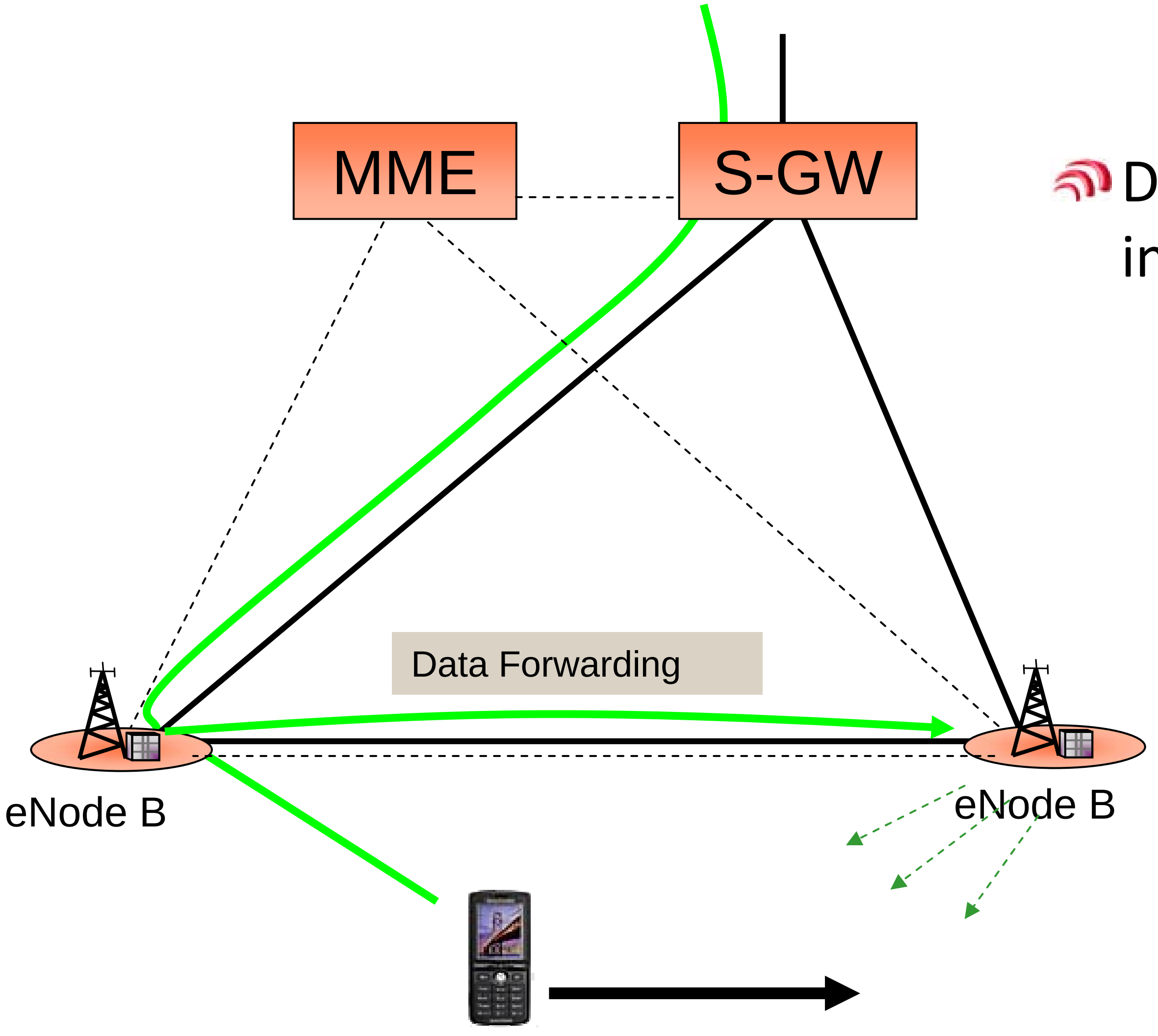
- HO request from source node
- Admission control
- HO Ack from target node

Connected State Mobility



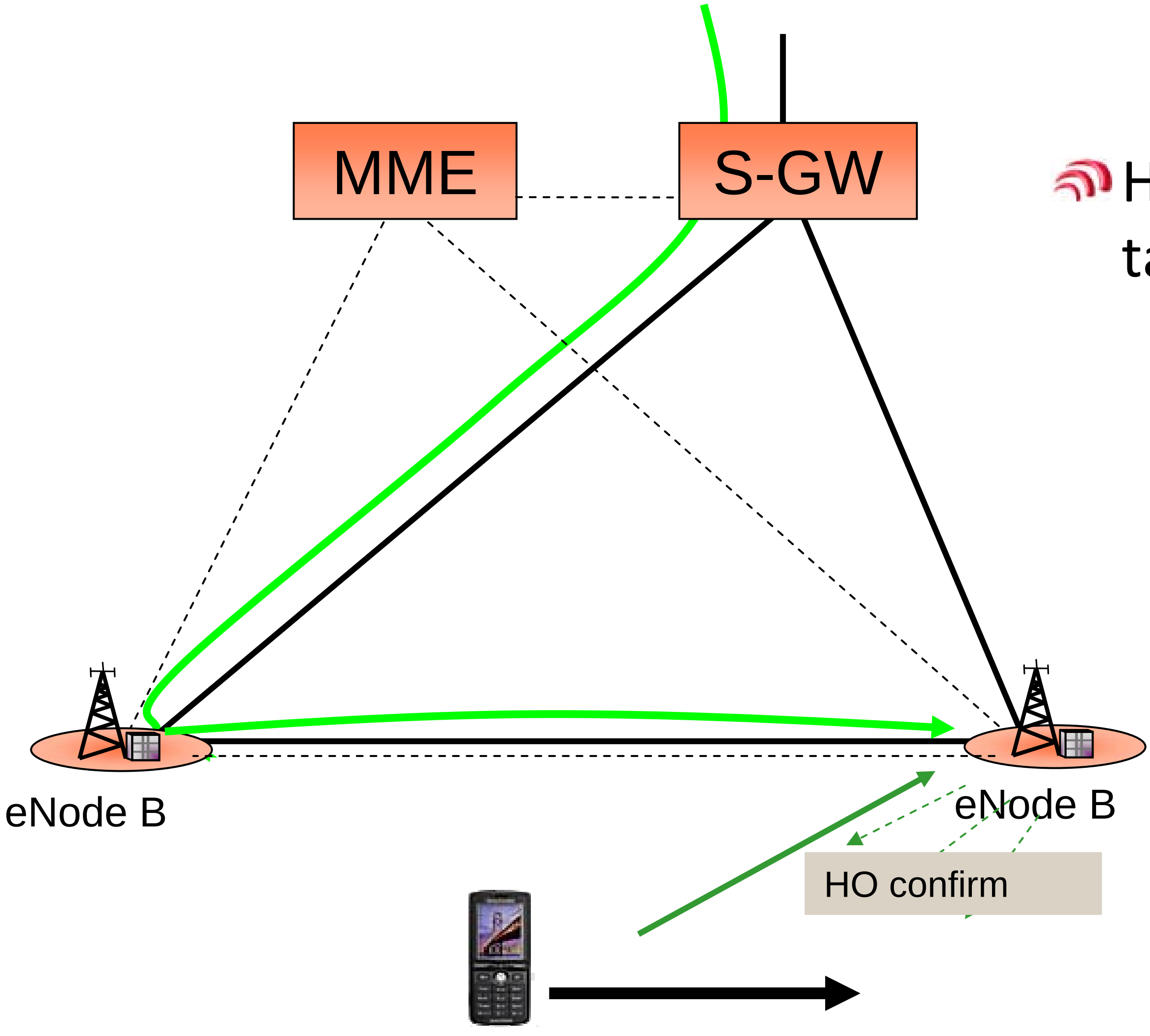
- HO Command from source node

Connected State Mobility



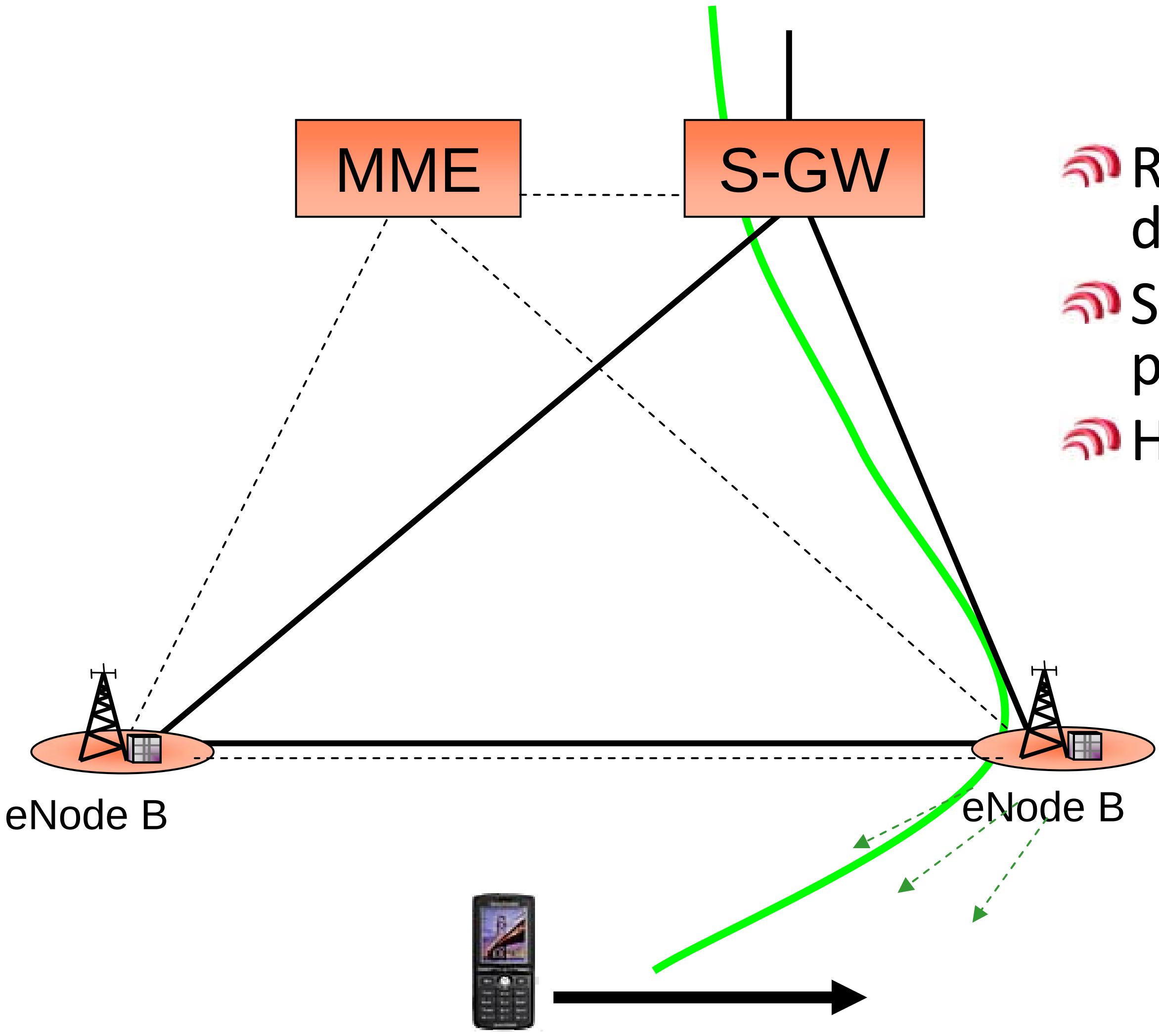
- Data forwarding initiated

Connected State Mobility



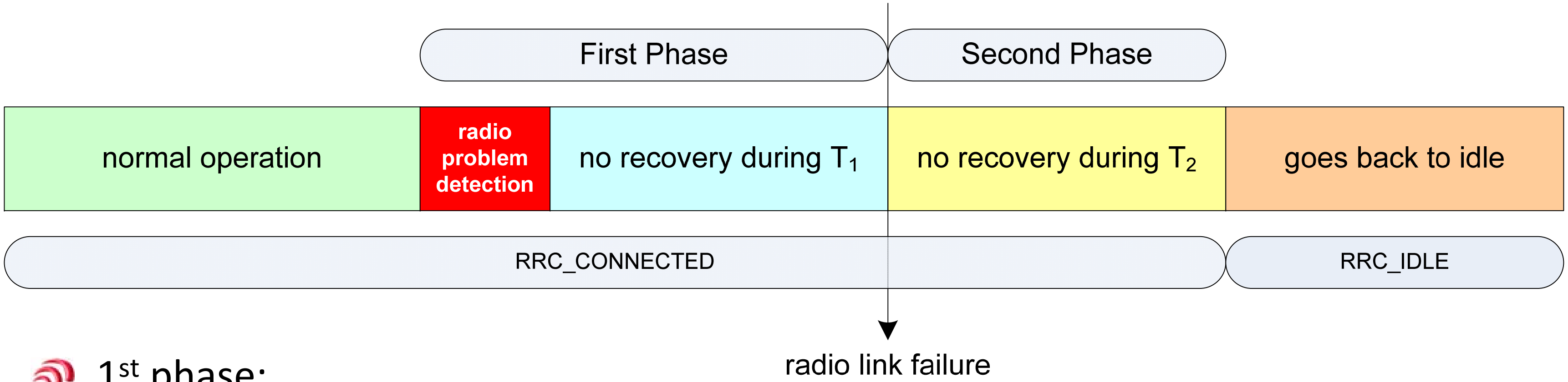
- Handover confirm to target node

Connected State Mobility



- Request EPC to switch data path
- S-GW switches data path
- HO completed

Radio Link Failure handling



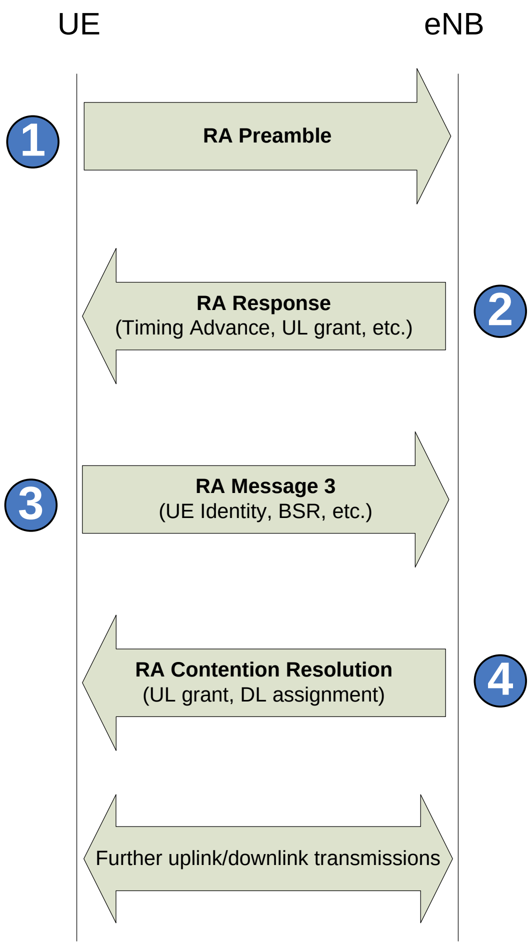
- 1st phase:
  - Layer 1 monitors downlink quality and indicates problems to RRC
    - RRC filters L1 indications and starts a timer
    - if no recovery within 1st phase, triggers 2nd phase
  - Layer 2 monitors random access attempts and indicates problems to RRC
    - RRC triggers 2nd phase
- 2nd phase – Radio Link Failure (RLF):
  - Possible recovery through an RRC Connection Reestablishment procedure
    - reestablishment may be performed in any cell to which the UE's context is made available
  - If no recovery within 2nd phase, UE goes autonomously to IDLE

Random Access procedure

- Four-step procedure to…
  - …establish uplink synchronization
  - …obtain UL-SCH resources
  - …obtain identity (C-RNTI)

1. Preamble transmission on PRACH
   - Timing estimation at eNodeB
2. Random access response
   - Timing Advance command
   - UL-SCH resource assignment for step 3
   - Temporary C-RNTI
3. Contention resolution
   - transmit terminal identity
   - also other data
4. Contention resolution
   - Echo terminal identity from step 3
   - also other signaling/data

- Also support for contention-free random access procedure ➡ only step 1 and 2 used



Priority access

- Access classes used to differentiate admittance in accessing a cell
  - UE associated to an access class for normal use
  - UE may also belong to an access class in the special categories, e.g., PLMN staff, social security services, government officials
- Access class barring
  - Access load can be controlled by use of access barring
  - For normal use, access barring rate and barring time could be broadcast in case of congestion
  - For the special categories, 1-bit barring status could be broadcast for each access class
  - Barring parameters could be configured independently for mobile originating data and mobile originating signaling attempts
  - For emergency calls, a separate 1-bit barring status is indicated

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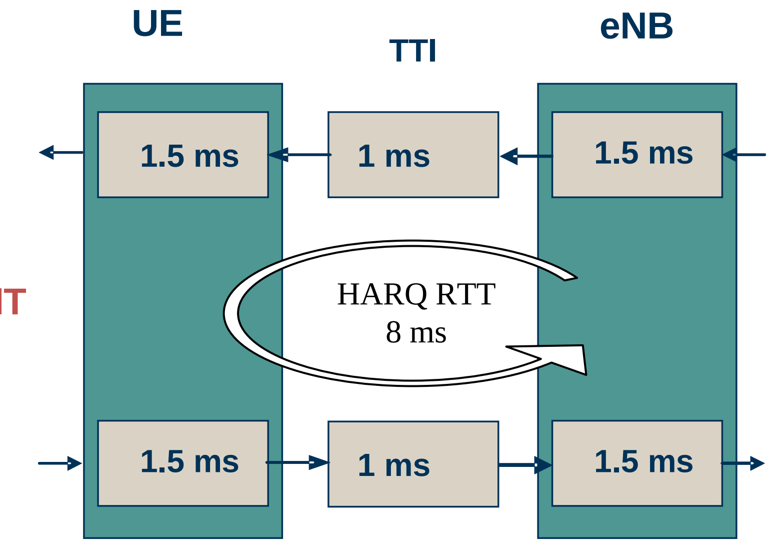
User plane latency

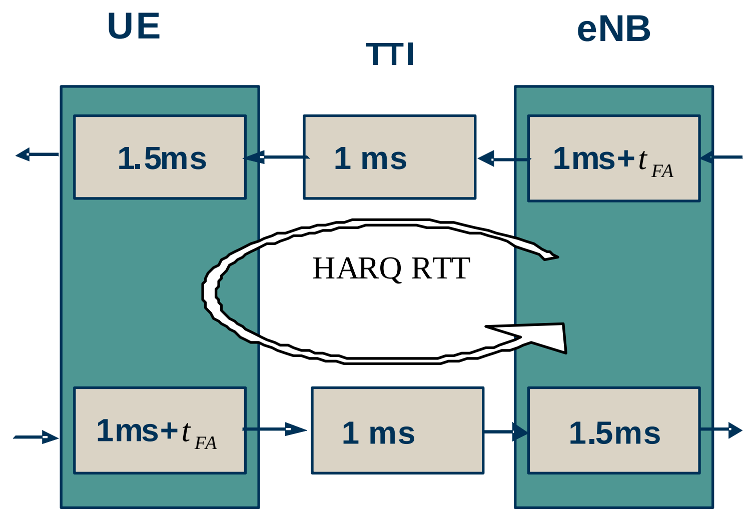
- User plane latency (FDD RIT)
  - 4ms when HARQ retransmission is not needed

FDD RIT



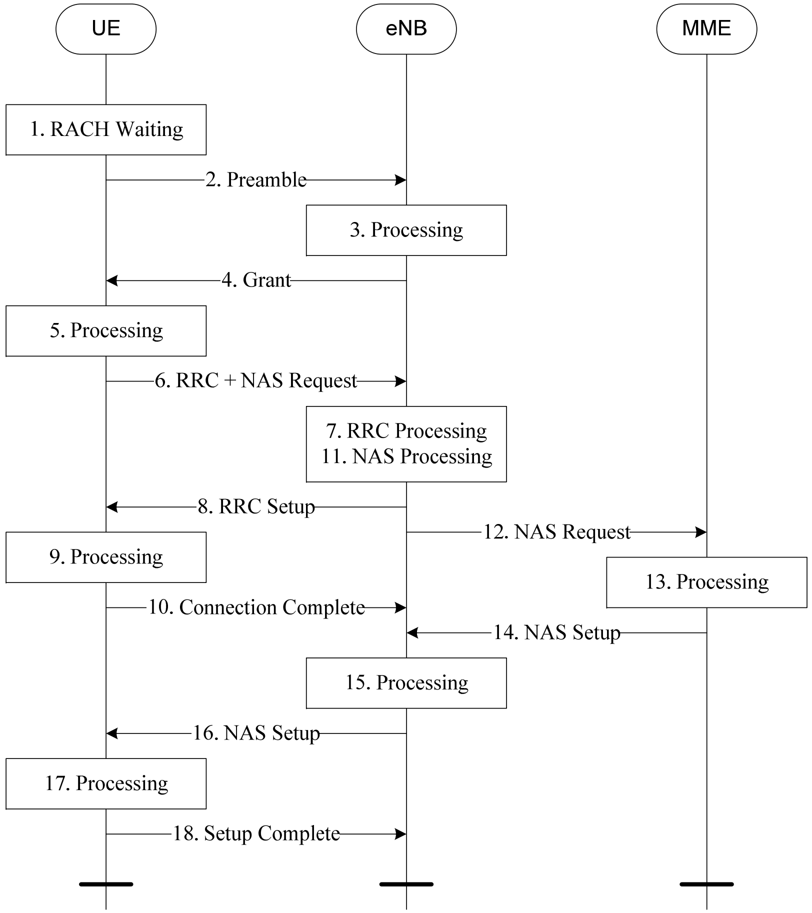
- User plane latency (TDD RIT)
  - Depends on UL/DL configuration and on whether UL or DL transmission
  - 4.9ms possible for uplink and downlink jointly when HARQ retransmission is not needed

TDD RIT



Control plane latency - IDLE→CONNECTED

A GLOBAL INITIATIVE

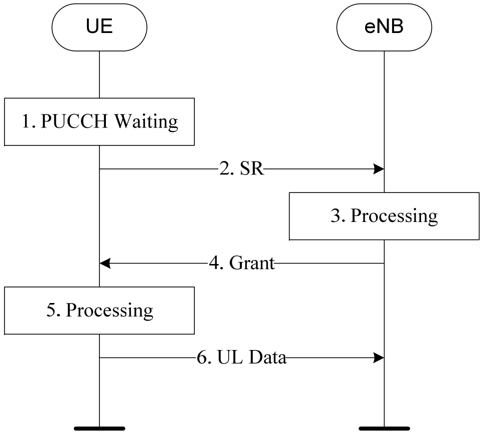


NOTE: LTE Rel-8 supports IDLE→CONNECTED latency of around 80ms and, hence, already meets the ITU requirement on C-plane latency for IDLE→CONNECTED transition

Step	LTE Advanced Description	Time [ms]
1	Average delay due to RACH scheduling period (1ms RACH cycle)	0.5
2	RACH Preamble	1
3-4	Preamble detection and transmission of RA response (Time between the end RACH transmission and UE's reception of scheduling grant and timing adjustment)	3
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Request)	5
6	Transmission of RRC and NAS Request	1
7	Processing delay in eNB (L2 and RRC)	4
8	Transmission of RRC Connection Set-up (and UL grant)	1
9	Processing delay in the UE (L2 and RRC)	12
10	Transmission of RRC Connection Set-up complete	1
11	*Processing delay in eNB (Uu → S1-C)*	
12	*S1-C Transfer delay*	
13	*MME Processing Delay (including UE context retrieval of 10ms)*	
14	*S1-C Transfer delay*	
15	Processing delay in eNB (S1-C → Uu)	4
16	Transmission of RRC Security Mode Command and Connection Reconfiguration (+TTI alignment)	1.5
17	Processing delay in UE (L2 and RRC)	16
	Total delay	**50**

Control plane latency – Dormant → Active

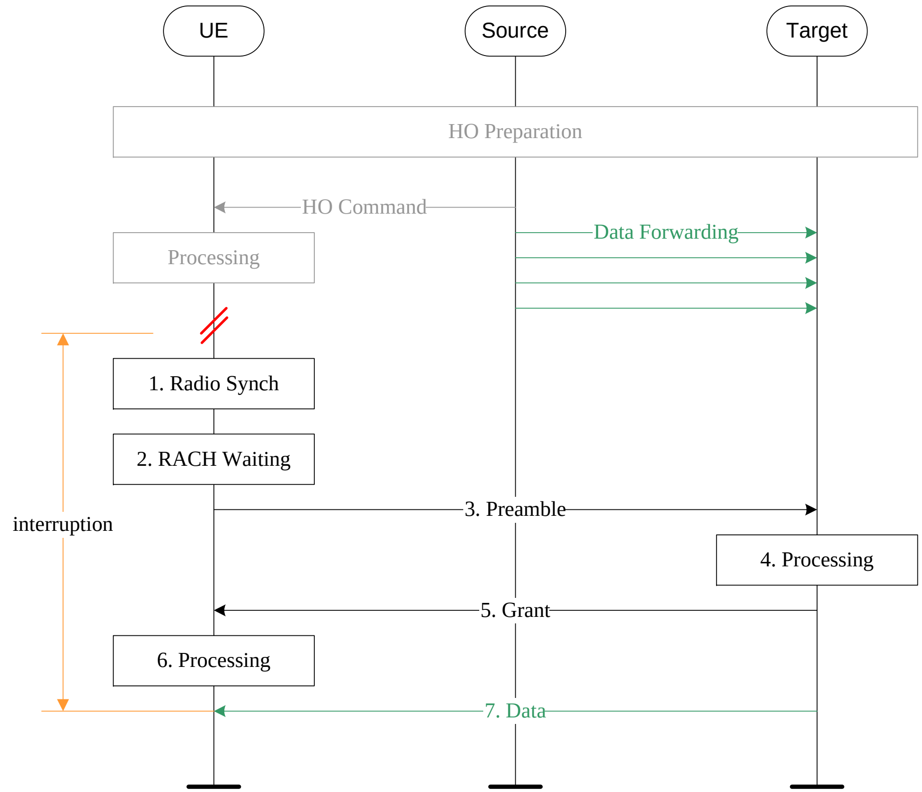
- Uplink initiated transition from dormant state (DRX substate) to active state (non-DRX substate) for synchronised UE; including first uplink data transmission.



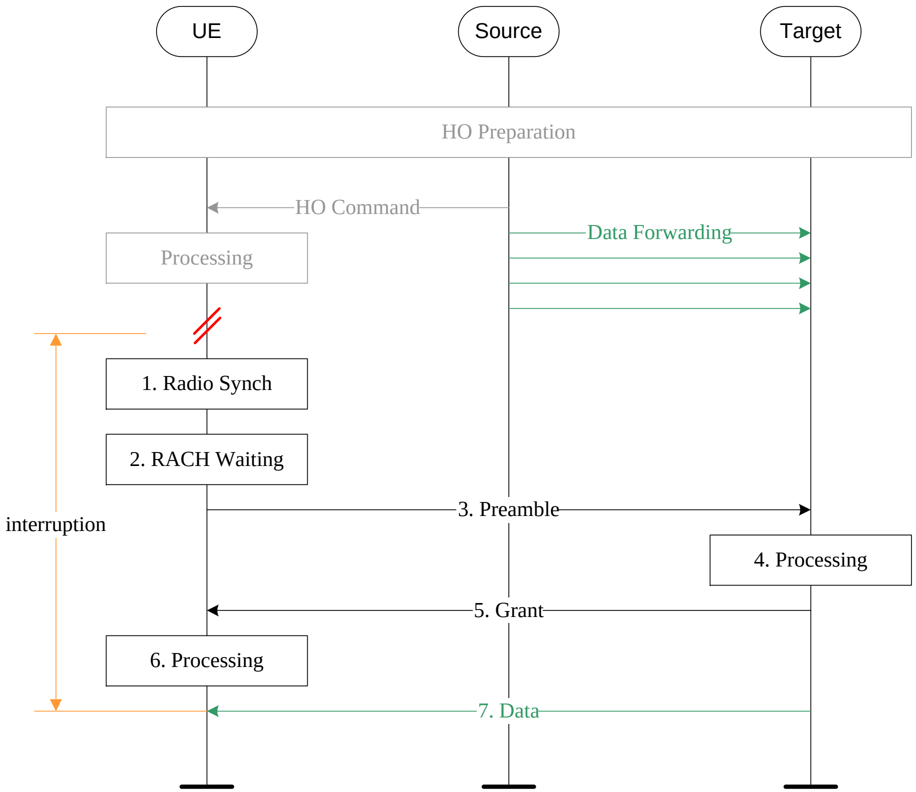
Step	LTE Advanced Description	Time [ms]
1	Average delay to next SR opportunity (1ms PUCCH cycle)	0.5
2	UE sends Scheduling Request	1
3	eNB decodes Scheduling Request and generates the Scheduling Grant (+ delay for nearest DL subframe)	3
4	Transmission of Scheduling Grant	1
5	UE Processing Delay (decoding of scheduling grant + L1 encoding of UL data)	3
6	Transmission of UL data	1
	Total delay	**9.5**

Handover interruption

- Intra-LTE inter-eNB handover
- Target cell already identified and measured by the UE
  - Fast radio synchronisation to target aided by previous measurement
- Data forwarding initiated before radio synchronisation to target cell and backhaul faster than radio
  - Forwarded data available in target when UE is ready to receive
  - Data forwarding does not affect overall delay



Handover interruption (cont'd)



Step	LTE Advanced Description	Time [ms]
1	Radio Synchronisation to the target cell	1
2	Average delay due to RACH scheduling period (1ms periodicity)	0.5
3	RACH Preamble	1
4-5	Preamble detection and transmission of RA response (Time between the end RACH transmission and UE's reception of scheduling grant and timing adjustment)	5
6	Decoding of scheduling grant and timing alignment	2
7	Transmission of DL Datta	1
	Total delay	**10.5**

Note: This delay does not depend on the frequency of the target in the typical case where the cell has already been measured by the UE

References

- TR 36.912: Feasibility study for Further Advancements for E-UTRA (LTE-Advanced)
- TS 36.300: E-UTRA and E-UTRAN Overall description
- TS 36.304: E-UTRA User Equipment (UE) procedures in idle mode
- TS 36.321: E-UTRA Medium Access Control (MAC) protocol specification
- TS 36.322: E-UTRA Radio Link Control (RLC) protocol specification
- TS 36.323: E-UTRA Packet Data Convergence Protocol (PDCP) specification
- TS 36.331: E-UTRA Radio Resource Control (RRC) Protocol specification

- Latest versions of these specifications can be acquired from:
  http://www.3gpp.org/ftp/Specs/html-info/36-series.htm