REV-090004

LTE Radio Layer 2, RRC and Radio Access Network Architecture

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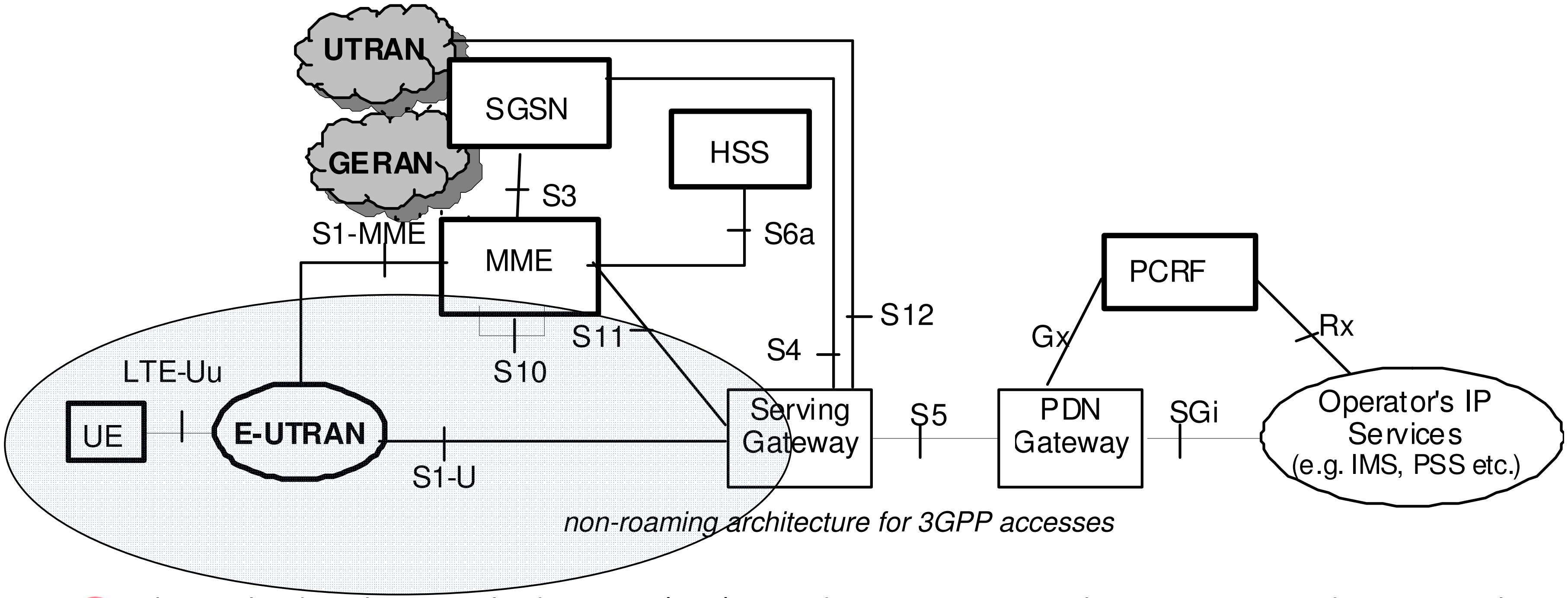
Outline

- E-UTRA overview
  - E-UTRAN architecture
- User plane
  - Bearer service
  - User plane protocol stack
  - User plane data flow
  - Security and PDCP
  - Reliable transport
  - Scheduling and QoS
  - DRX
- Control plane
  - Control plane protocol stack
  - Connection control
  - RRC states model
  - Connected state mobility
- Some highlights
  - Interoperability with legacy systems
  - Self Organizing Networks
  - UE Positioning
  - Multimedia Broadcast
  - Latency evaluations
  - LTE-Advanced features

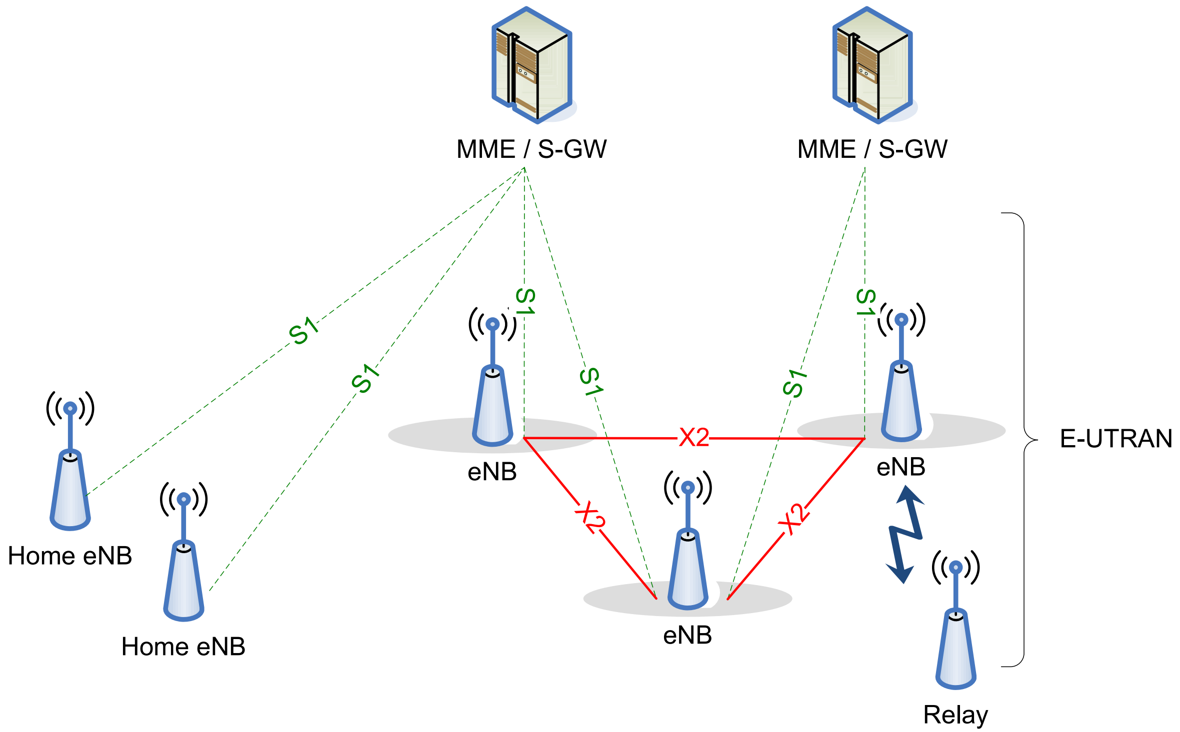
The Evolved Packet Switched System (EPS)



non-roaming architecture for 3GPP accesses

- The Evolved Packet Switched System (EPS) provides IP connectivity between a UE and an external packet data network using the **Evolved-Universal Terrestrial Radio Access Network** (E-UTRAN)
- Consists of an Evolved Packet Core (EPC) and Evolved-UTRAN (E-UTRAN)
- The focus of this presentation is on E-UTRAN functions

E-UTRAN architecture



- E-UTRAN consists of eNBs, home eNBs and Relays providing the E-UTRA user plane and control plane protocol terminations towards the UE
  - Fully distributed radio access network architecture
- eNBs, and home eNBs are connected by means of the S1 interface to the Evolved Packet Core (EPC)
  - Optionally a home eNB Gateway may be used
- eNBs may be interconnected with each other by means of the X2 interface
  - X2 supports enhanced mobility, inter-cell interference management, and SON functionalities
- Relays connect either via an in-band or out-of-band wireless backhaul

User Plane

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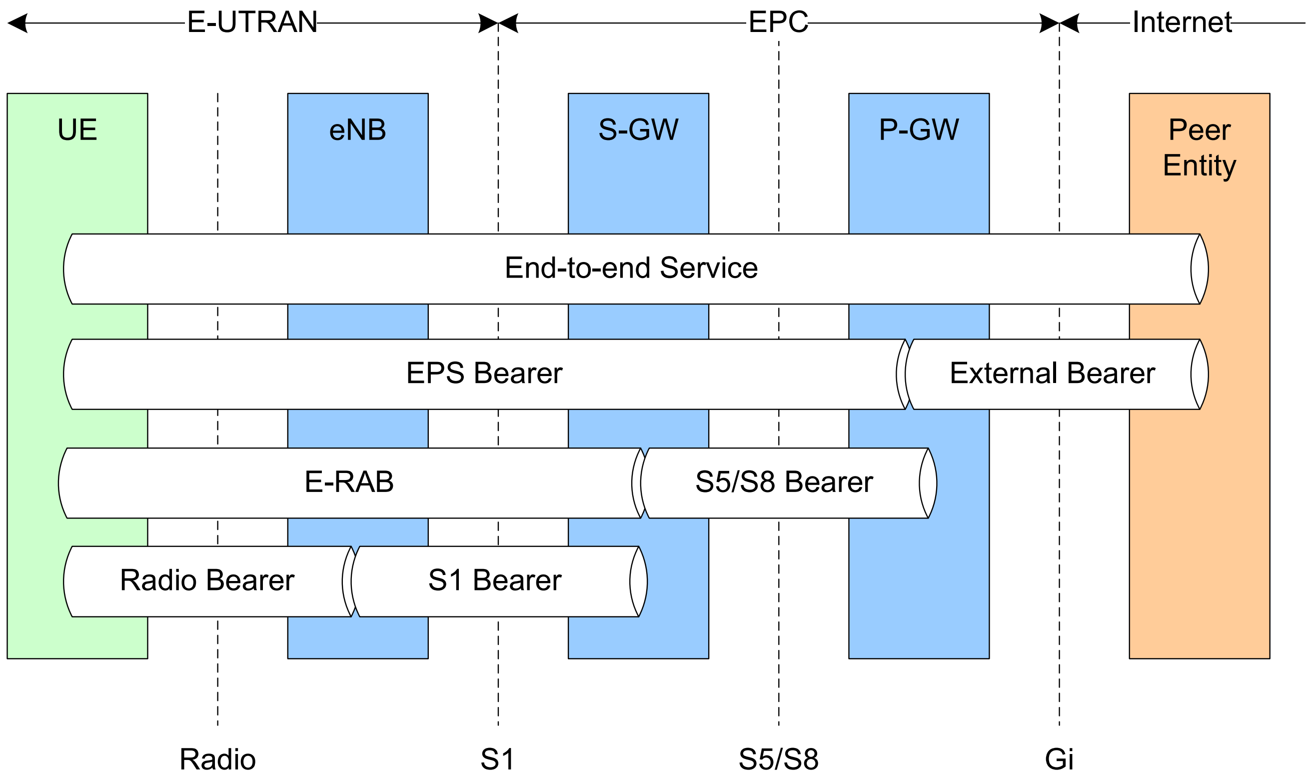
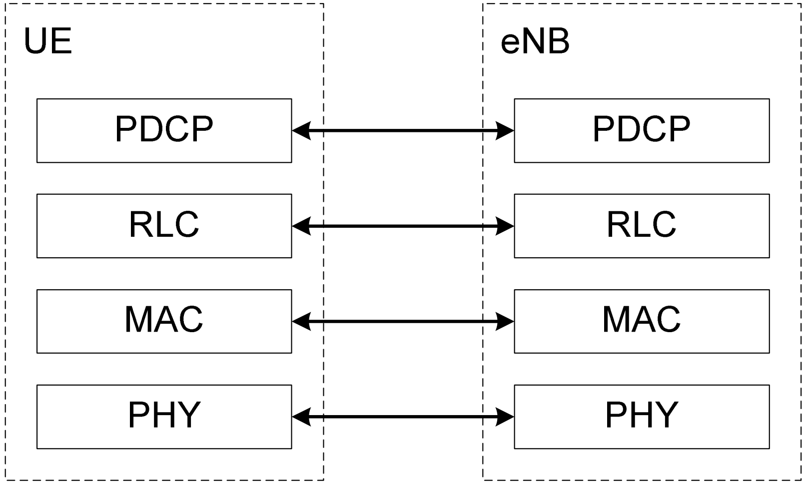
EPS Bearer Service Architecture



There is a one-to-one mapping EPS Bearer ⇔ E-RAB ⇔ Radio Bearer over the radio interface

User plane protocol stack



- PDCP (Packet Data Convergence Protocol)
  - Ciphering
  - Integrity protection‡
  - In-sequence delivery and retransmission of PDCP SDUs for AM Radio Bearers at handover
  - Duplicate detection
  - Header compression using the RoHC protocol†

TS 36.323

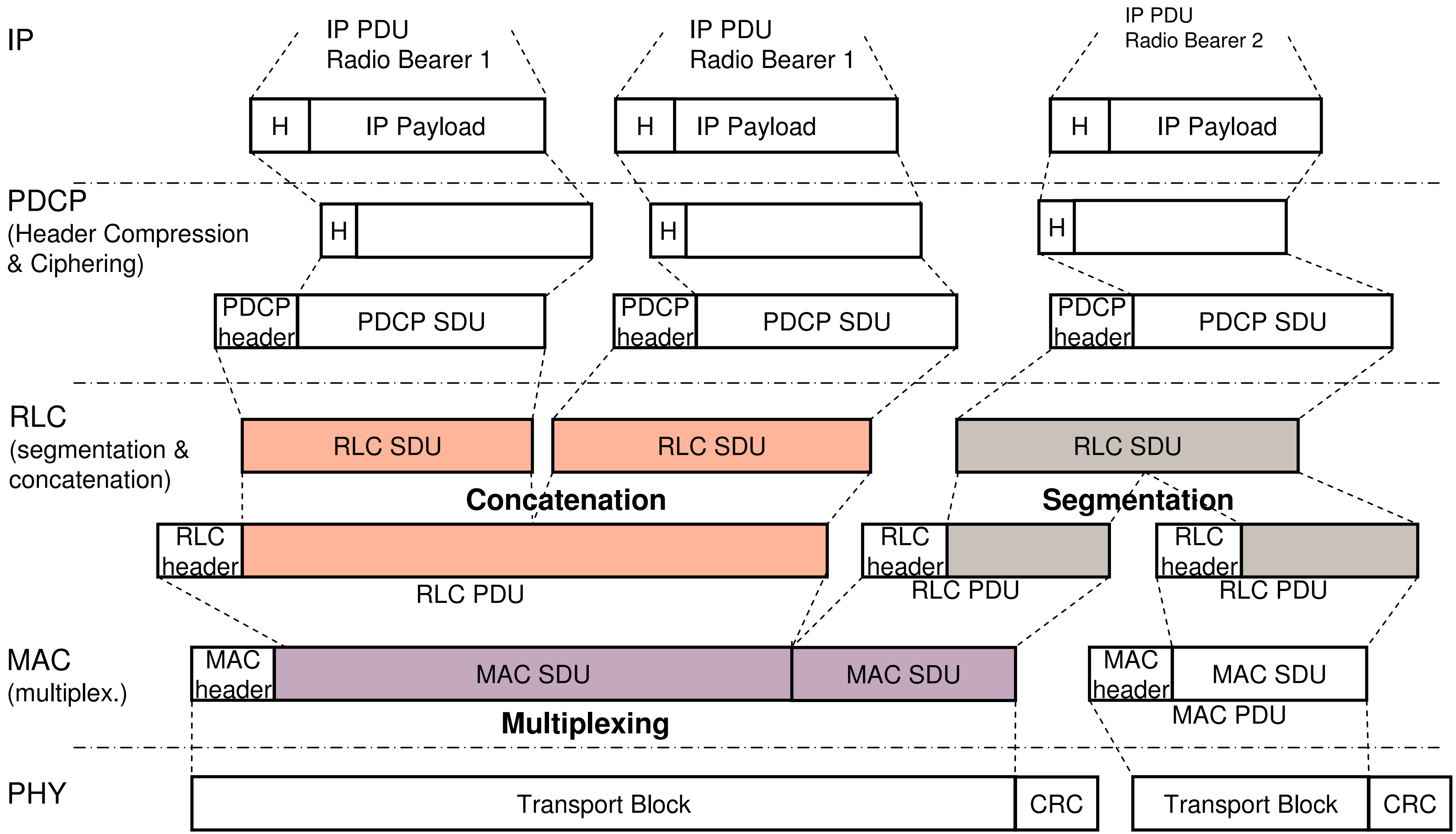
TS 36.322

- RLC (Radio Link Control)
  - Error Correction through ARQ
  - (re)-Segmentation according to the size of the TB
  - Concatenation of SDUs for the same radio bearer
  - In-sequence delivery
- MAC (Media Access Control)
  - Multiplexing/demultiplexing of RLC PDUs
  - Scheduling Information reporting
  - Error correction through HARQ
  - Logical Channel Prioritisation

TS 36.321

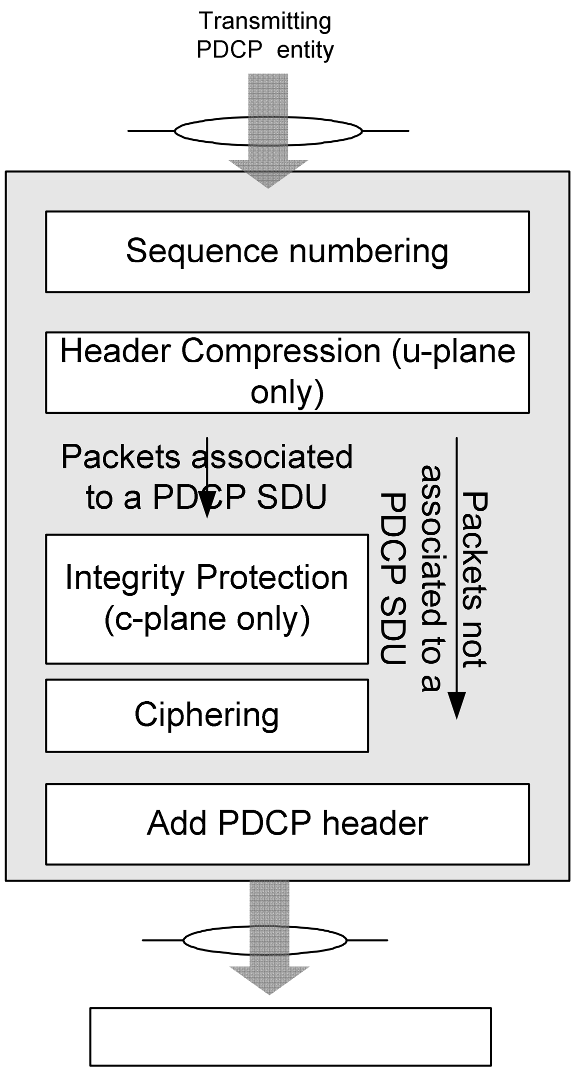
†) for U-plane ‡) for C-plane

User Plane data flow (transmitter)



Security
Ciphering and Integrity Protection

- Access Stratum (AS) security functions provided by PDCP controlled by RRC
  - 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): signaled over the air
- 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
- Integrity protection
  - for C-plane radio bearers (Signaling Radio Bearers)
  - 32-bit Message Authentication Code (MAC-I)



Scheduling

- Input - QoS parameters for EPS-bearers
  - QoS Class Identifier (QCI) – per bearer
    - Scalar value which identifies a particular service or class of services
  - Guaranteed Bit Rate (GBR), Prioritized Bit Rate (PBR) – per bearer
    - Used to accept/modify/drop bearers in case of resource limitation
  - Allocation and Retention Policy (ARP) – per bearer
  - Aggregate Maximum Bit Rate (AMBR) – per group of bearers
    - Aggregate maximum bit rate per group of bearers of a single user, Only for non-GBR bearers
- Scheduler residing in eNB with objective of:
  - Fulfilling above "QoS Contracts“, while
  - maximizing cell throughput and providing Fairness,
- Scheduling Information from UE includes.:
  - Channel Quality Indication; Buffer Status Report; Power Headroom Report; Uplink Sounding.
- Scheduling for uplink is partially specified
  - Logical channel prioritization and avoid starvation
- QoS framework with per bearer granularity supports wide range of services for a given UE

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 (VoIP)
    - 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
    - Activation/Deactivatoin with a special assignment/grant

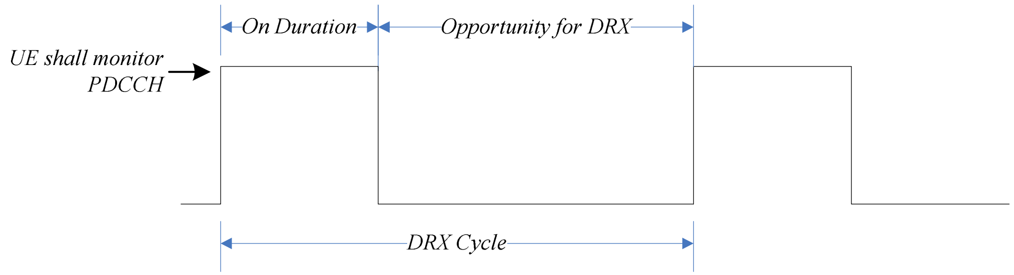
Reliable transport
Retransmission protocols

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

†) RLC AM/TM (Acknowledged Mode/Transparent Mode) only

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
  - UE autonomous transitions between states, based on timers and events

Control Plane

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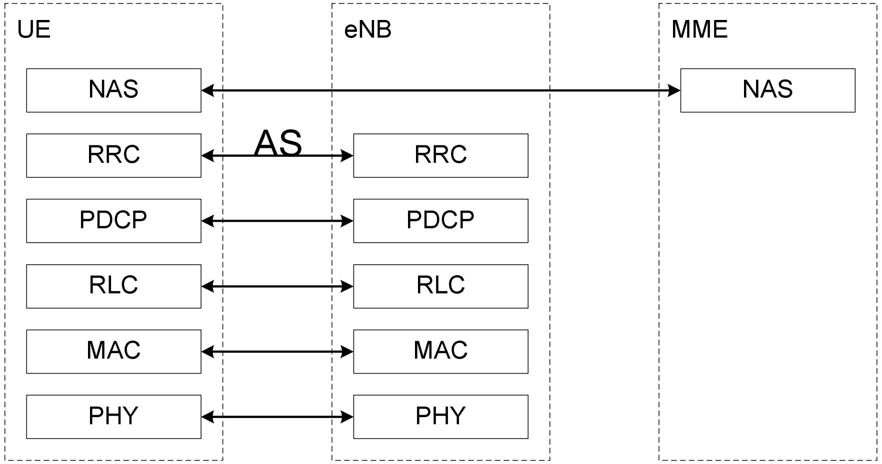
Control plane protocol stack

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



TS 36.331

- RRC (Radio Resource Control)
  protocol performs:
  - 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);
  - NAS direct message transfer between UE and NAS.
  - Security functions including

Connection Management

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

RRC State Models

- Only two RRC states
  - Idle and Connected
- The Idle mode minimized battery consumption
- The Connected mode is suitable for data transfer

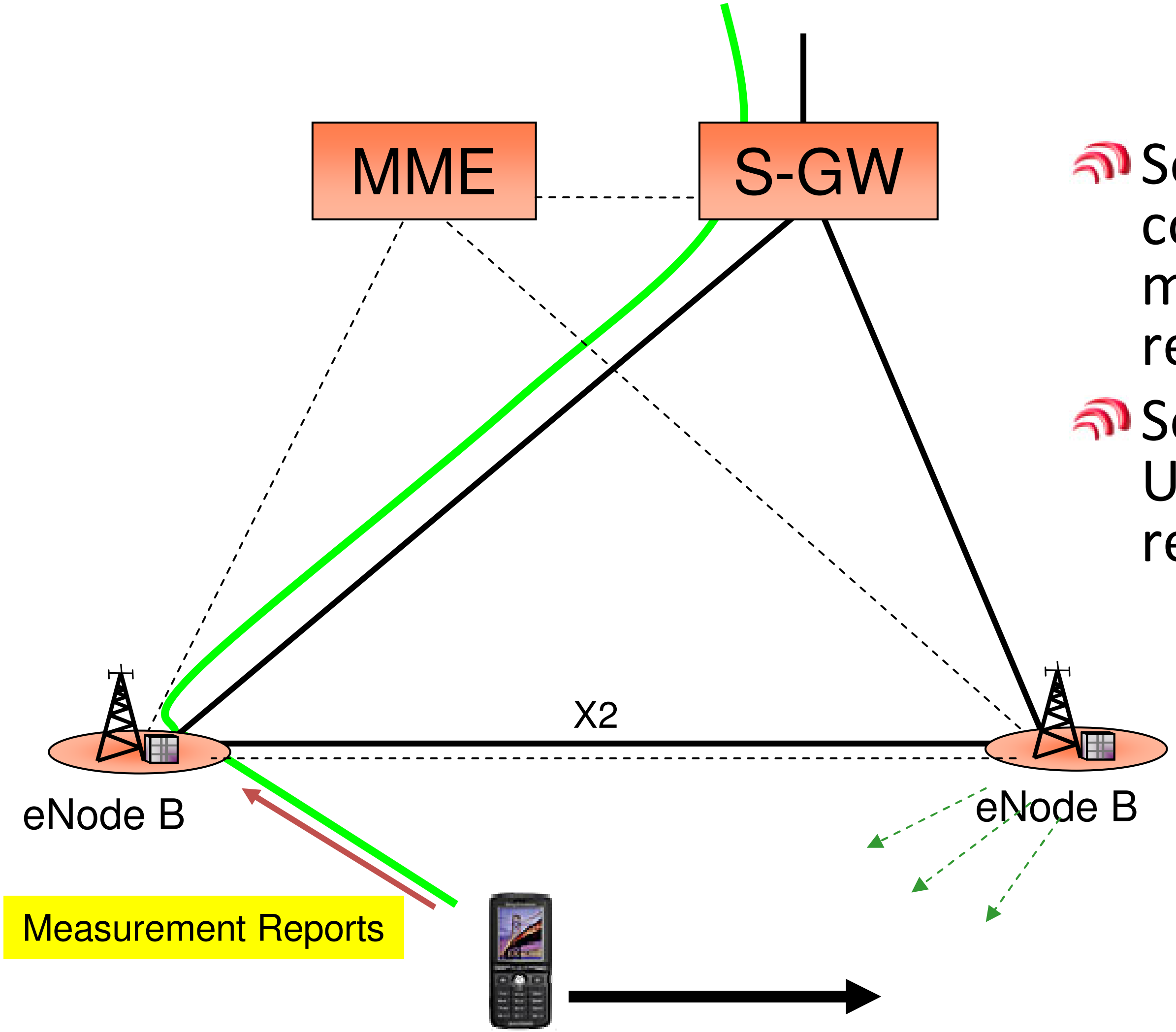
Idle Mode

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

Connected Mode

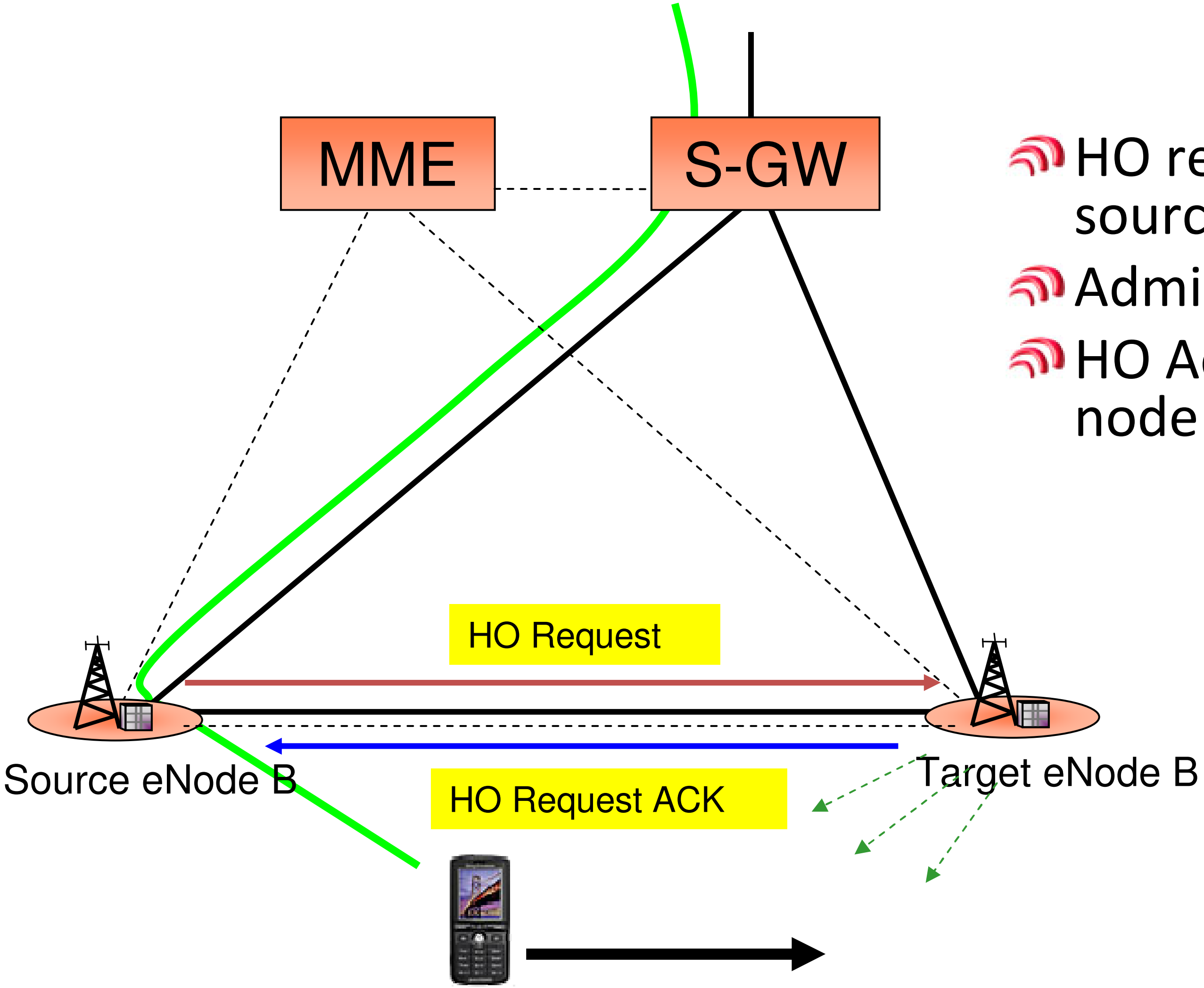
- UE known in EPC and E-UTRAN/eNB; ”context” in eNB;
- Mobility is UE-assisted, network-controlled
- Unicast data transfer possible
- UE location known on cell level
- Discontinuous Data Reception (DRX) supported for power saving

Connected State Mobility



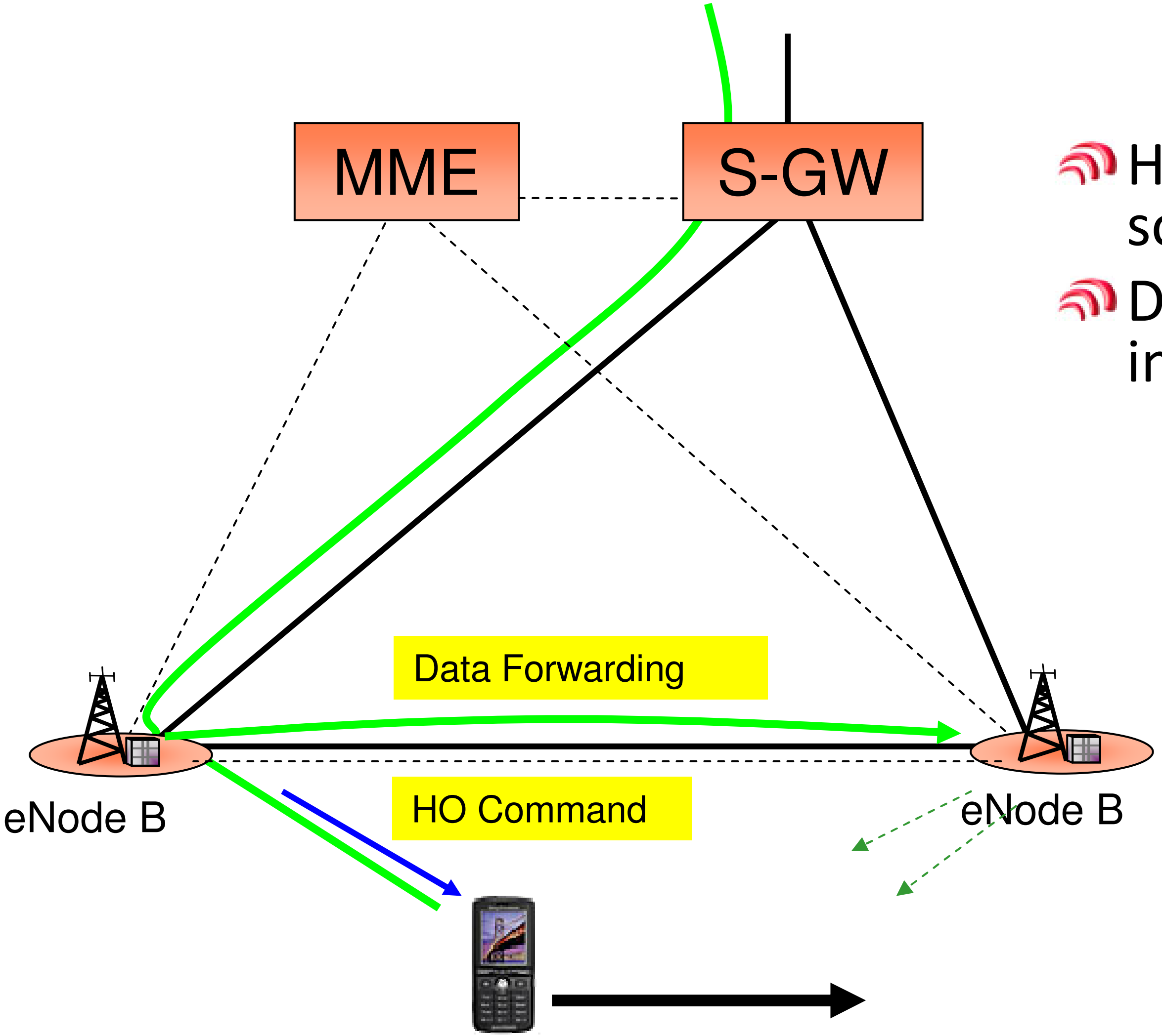
- Source eNodeB configures UE measurements and reporting
- Source eNB receives UE measurement report

Connected State Mobility



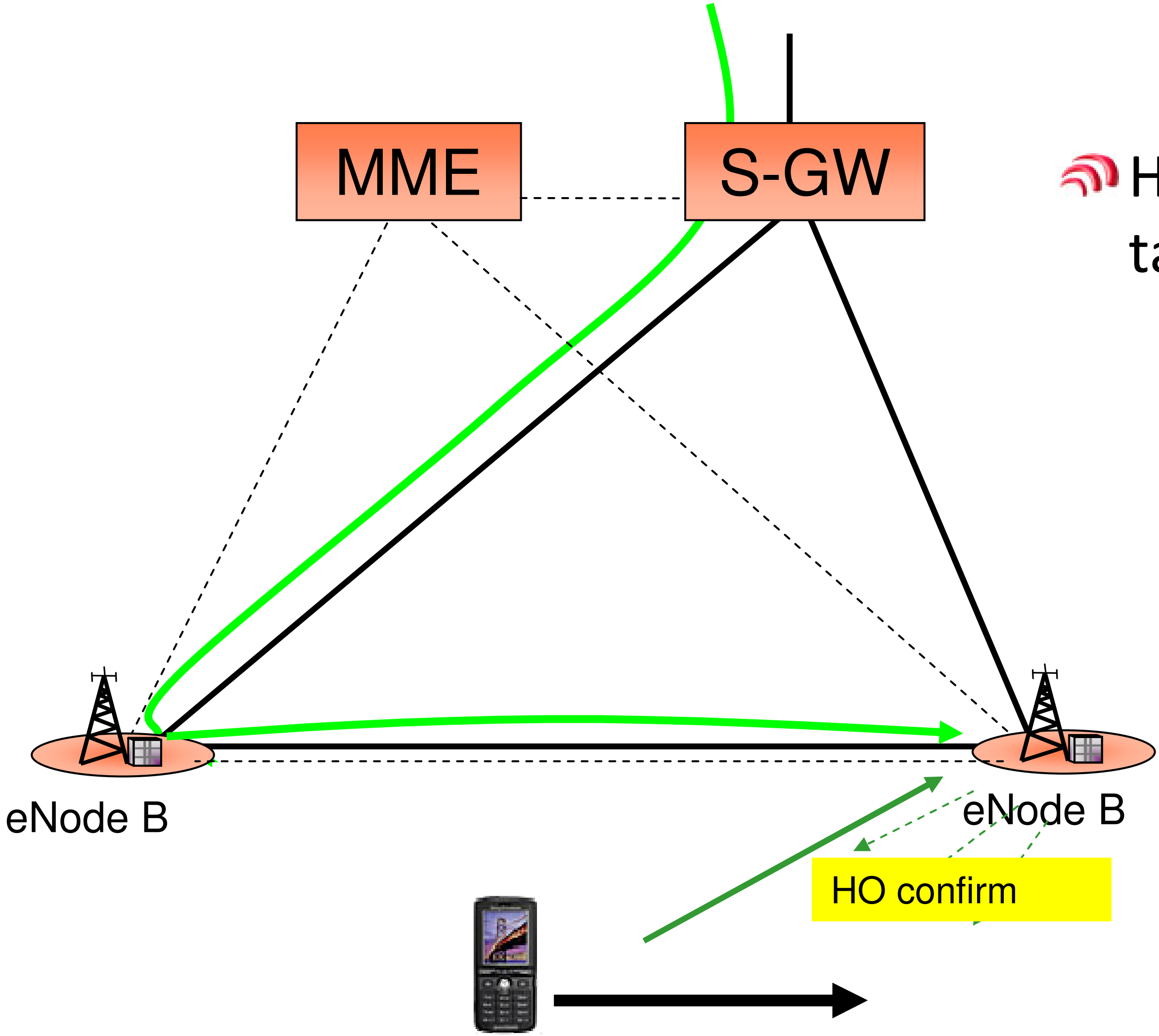
- HO request from source node
- Admission control
- HO Ack from target node

Connected State Mobility



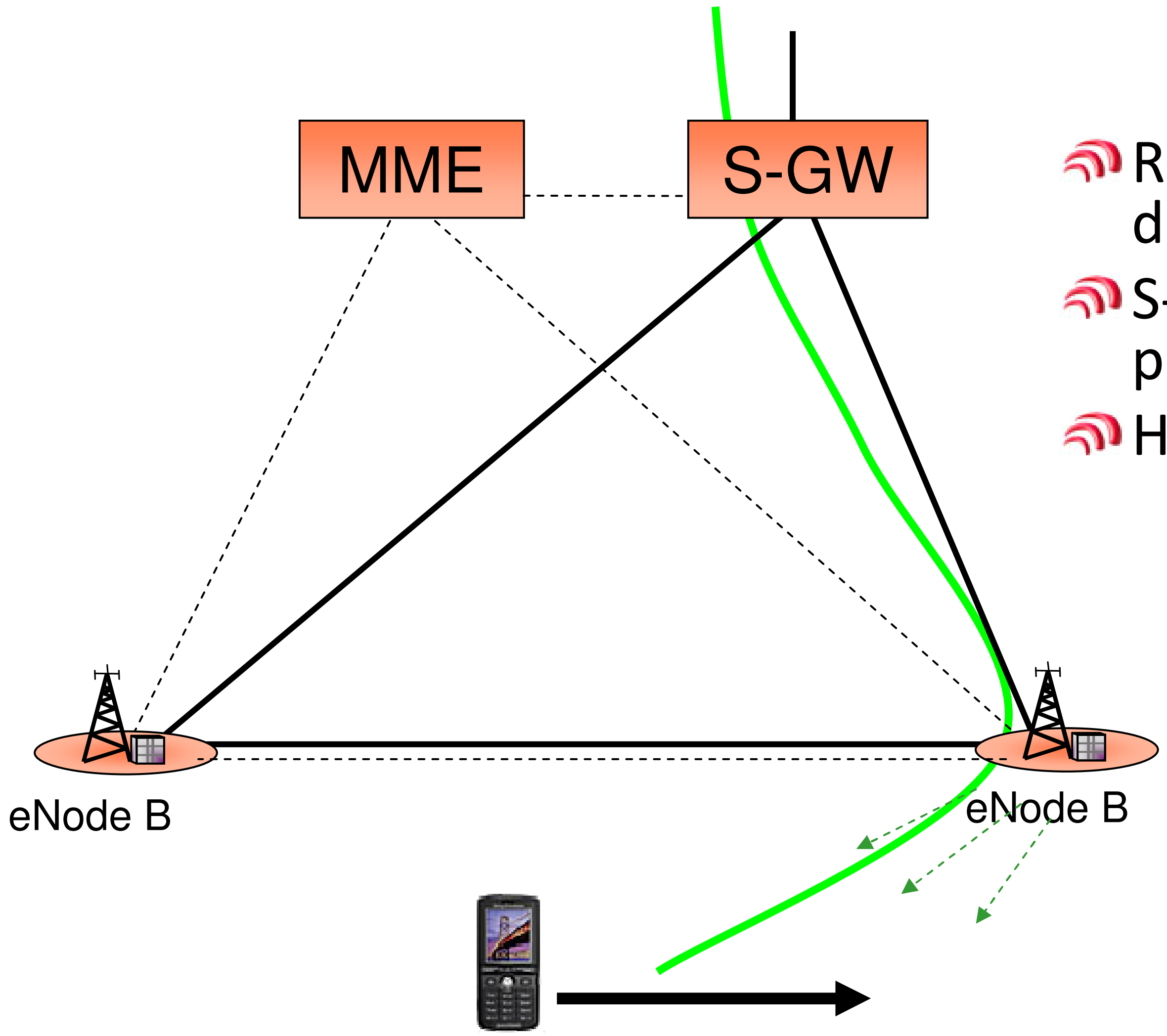
- HO Command from source node
- Data forwarding initiated

Connected State Mobility



- Handover confirm to target node

Connected State Mobility



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

Some highlights

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Inter-operability with legacy systems

- E-UTRAN inter-operates with GERAN, UTRAN, 1xRTT and eHRPD
  - Inter-operability with other Radio Access Technologies (RATs) is possible at the IP level.
- Different inter-operability mechanisms have been standardized to cater for different deployment options
  - Inter-RAT handover
  - Network Assisted Cell Change (NACC)
  - Single-Radio Voice Call Continuity (SR-VCC)
  - Circuit Switched (CS) fallback

Inter-operability with legacy systems (cont'd)

- Inter-RAT handover
  - Framework allowing optimized (seamless/lossless) handovers of packet data sessions from E-UTRAN to UTRAN/GERAN and from E-UTRAN to eHRPD
- Network Assisted Cell Change (NACC)
  - Framework allowing **handovers of packet data sessions** from E-UTRAN to GERAN, for GERAN networks **that do not support PS handover**
- Single-Radio Voice Call Continuity (SR-VCC)
  - Framework allowing the network to handover a voice call **from the IM CN Subsystem (PS domain) to the CS domain of a legacy system**
    - The function allows to perform a PS to CS domain transfer together with a radio link handover
  - SR-VCC handovers supported from E-UTRAN to UTRAN/GERAN and E-UTRAN to 1xRTT
- CS fallback
  - Framework allowing the provisioning of voice services by reuse of CS infrastructure when the UE is served by E-UTRAN
    - The function allows to perform tunneling of CS domain paging over E-UTRAN, and subsequent handover to an overlapping CS-capable legacy RAT to handle the voice call over CS
  - CS fallback supported from E-UTRAN to GERAN/GERAN and E-UTRAN to 1xRTT

Self Organizing Networks (SON)

- E-UTRAN supports multiple SON functions
  - Allow to automate network configuration/optimization processes and thus reduce the need for centralized planning and human intervention

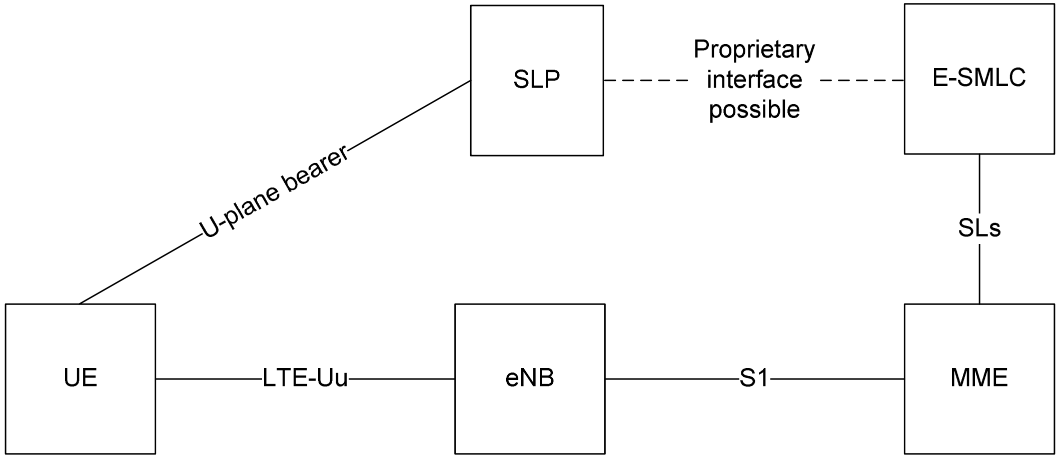
- SON functions are mostly enabled
  - by the exchange of information between neighbour eNBs
  - by assistance from UE (reports)

- (the standardized part of SON is only the tip of the iceberg)

SON functions supported in the standard

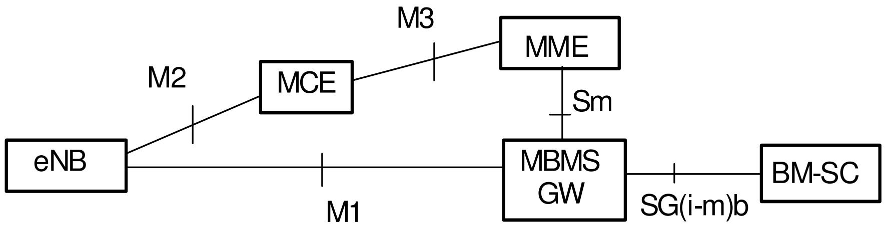
- Automatic Neighbor Relation function
  - Allows the eNB to build and maintain its neighbour relations based on UE reports (Function relies on connected mode UEs that can read and report the Cell Global Identity (CGI) of a neighbour cell)
- Automatic PCI selection
  - Allows the eNB to select its own PCI (Physical Cell Identifier) based on UE reports and information received from neighbour eNBs
- Dynamic configuration of X2/S1 interfaces
  - Allows the eNB to dynamically configure the S1-MME interface with the serving MMEs and the X2 interface with neighbour eNBs
- RACH parameters optimization
  - Allows neighbour eNBs to exchange information about their used PRACH resources (and thus avoid interference and RACH collisions)
- Mobility parameters optimization
  - Allows to adapt the mobility-related parameters of an eNB to enhance mobility robustness or for load-balancing reasons
- Ongoing work on Minimization of Drive Test
  - Any UE can log and report about the network

UE positioning in LTE



- EPS supports both a C-plane based and U-plane based positioning mechanism to cater for different deployment options
  - Both mechanisms operate via end-to-end protocol between UE and a positioning server i.e. E-SMLC (C-plane)/SPL (U-plane)
  - The same end-to-end protocol is used in both mechanisms: the LTE Positioning Protocol (**LPP**)
- LPP acts as a method-agnostic supporting protocol for various UE positioning methods
  - OTDOA (downlink positioning method based on measured time differences observed by the UE from different eNode Bs)
  - A-GNSS (satellite positioning: GPS and similar systems)
  - Enhanced Cell ID methods (cell level)

Broadcast support in E-UTRAN



- The LTE Multimedia Broadcast and Multicast System uses the Single Frequency Network (SFN) mode of operation to enable efficient multi-cell transmission of E-MBMS services
  - Synchronized transmissions from multiple cells (seen as a single transmission by a UE)
    - Single transmission mode (i.e. no HARQ or RLC repetitions)
  - The MCE coordinates multi-cell transmission
  - Content synchronization is ensured via SYNC protocol running between eNB and Broadcast Multicast Service Centre (BM-SC)

- MBSFN mode of operation is provided only on a frequency layer shared with non-MBMS services
  - Cells supporting both unicast and MBMS transmissions are called "MBMS/Unicast-mixed" cells

- E-MBMS reception is possible for UEs in Idle or Connected state, in parallel with unicast operation

Latency evaluations by RAN2

- User-plane one-way latency
  - FDD
    - 4ms when HARQ retransmission is not needed
  - TDD
    - 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
- Idle -> Connected transition
  - LTE: 80ms
  - LTE-A: 50ms
- Inter-eNB Handover interruption time
  - 10.5ms

LTE Advanced features

- 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
- 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

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
- TS 36.401: E-UTRAN Architecture description
- TS 36.412: E-UTRAN S1 signaling transport

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

Thank you !

- Time for questions

Backup slides

Functional split - MME

- MME host the following functions:
  - Non Access Stratum (NAS) signalling
  - NAS signalling security
  - AS security control
  - Inter CN node signalling for mobility between 3GPP access networks
  - Tracking Area list management
  - 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 PWS (which includes ETWS and CMAS) message transmission
  - UE reachability in idle state (including control and execution of paging retransmission)

Functional - split S-GW, PDN-GW

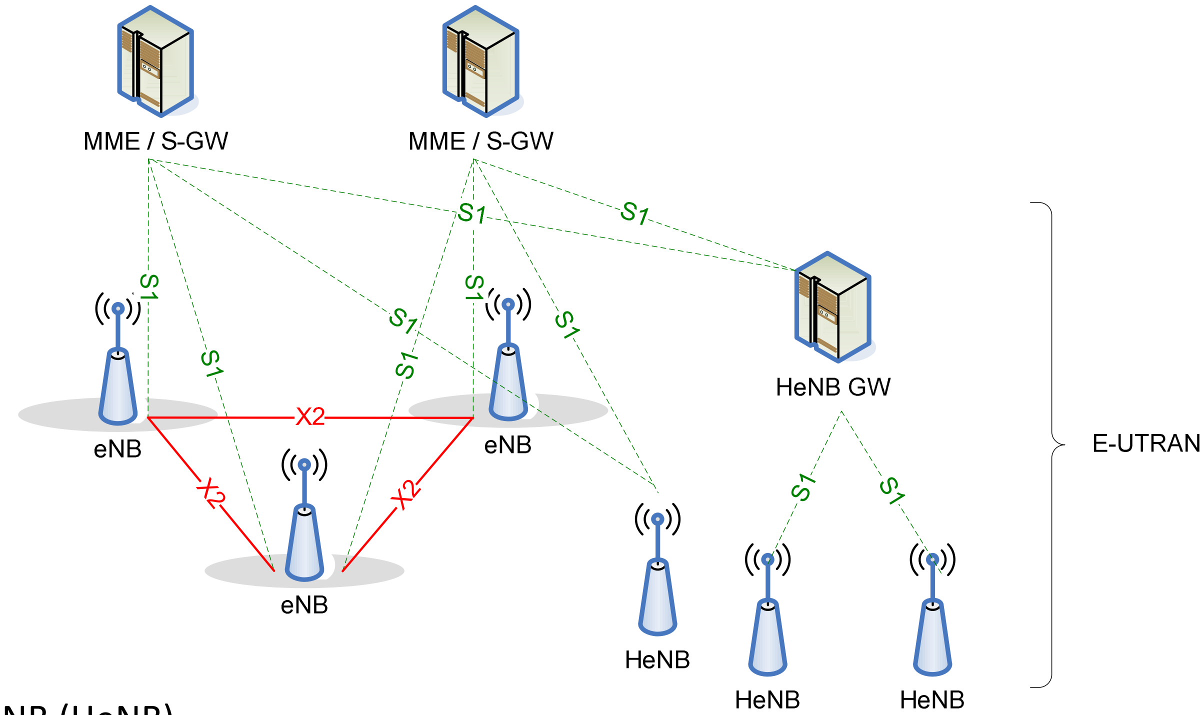
- Serving Gateway (S-GW) hosts the following functions:
  - The local Mobility Anchor point for inter-eNB handover
  - Mobility anchoring for inter-3GPP mobility
  - E-UTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure
  - Lawful Interception
  - Packet 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

- PDN Gateway hosts the following functions:
  - Per-user based packet filtering (by e.g. deep packet inspection)
  - Lawful Interception
  - 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
  - Credit control for online charging

Functional split - eNB

- eNB hosts the following functions:
  - Radio Resource Management functions
    - Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Scheduling of UEs in both uplink and downlink
  - Measurement and measurement reporting configuration for mobility and scheduling
  - Access Stratum (AS) security
  - 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)
  - Scheduling and transmission of PWS (which includes ETWS and CMAS) messages (originated from the MME)

Home eNB



- Home eNB (HeNB)
  - Customer-premises equipment that uses the operator's licensed spectrum
  - Can be used to enhance network coverage/capacity
  - Includes the functions of an eNB as well as some additional HeNB-specific configuration/security functions
- HeNB-Gateway (HeNB GW)
  - Addresses the issue of supporting a large number of S1 interfaces in the core network

Home eNB (cont'd)

- Three different access modes are defined for HeNBs
  - Closed access mode: HeNB provides services only to its associated Closed Subscriber Group (CSG) members
  - Hybrid access mode: HeNB CSG members' service is prioritized over non-members
  - Open access mode: HeNB appears as a normal eNB

- Two categories of parameters are broadcast by HeNB cells operating in closed/hybrid acces mode:
  - Parameters to support the UE in the identification of closed/hybrid cells
    - CSG Indicator, CSG Identity (CSG ID), HNB Name
  - Parameters to support an efficient search of closed/hybrid cells at the UE
    - Range of Physical Cell-IDs (PCIs) reserved for closed cells

- CSG provisioning functions manage how the CSG information is stored in the UE and the network
  - Provisioning of the CSG lists on the UE to avoid forbidden closed cells
  - Network storage of the CSG subscription for access control, per CSG charging, etc.

- Mobility management supports different access modes
  - Access Control procedures for establishing a connection and for handover
  - Differentiating between a member and a non-member at a hybrid cell
  - Automatic (re-)selection in idle mode if the CSG ID broadcast by the closed or hybird cell is in the UE CSG lists
  - Manual user selection of a closed or hybrid cell

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

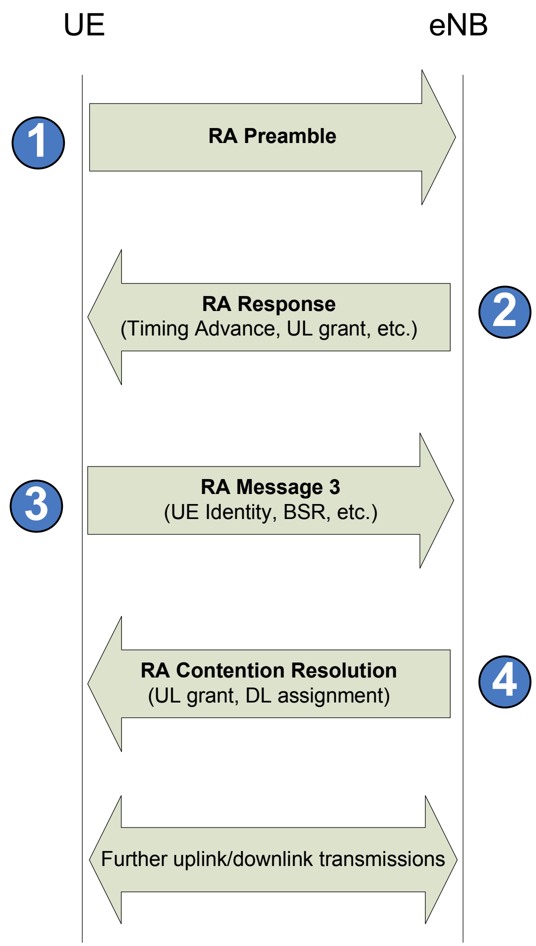
- Access class barring
  - Access load can be controlled by use of access barring
  - For normal use, access barring rate and barring time may be broadcast in case of congestion
  - For the special categories, 1-bit barring status may be broadcast for each access class
  - Barring parameters may be configured independently for mobile originating data and mobile originating signaling attempts
  - For emergency calls, a separate 1-bit barring status is indicated

Random Access procedure

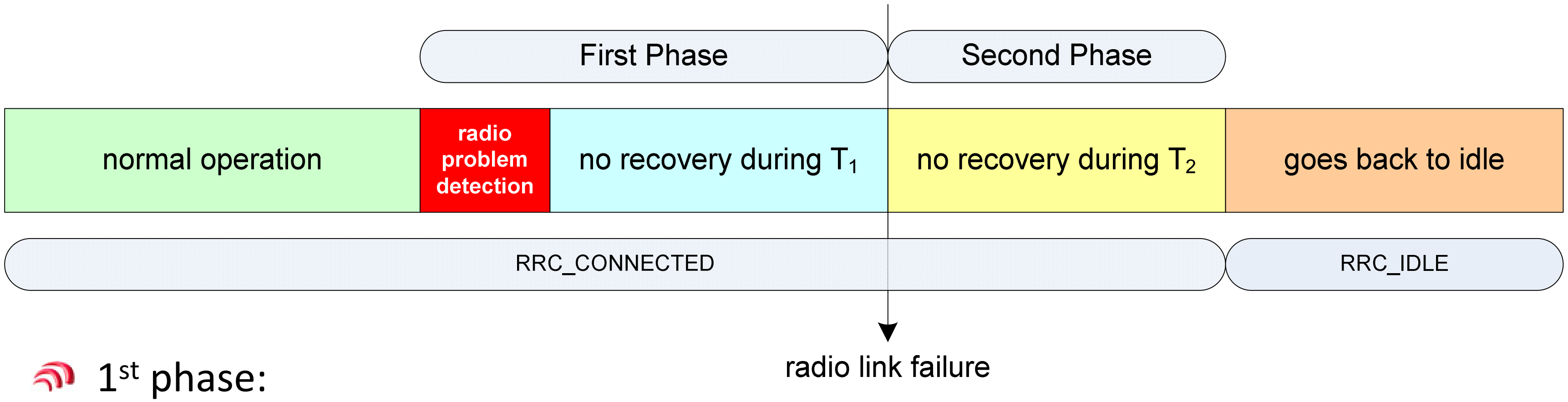
- Four-step procedure used for
  1. Establish/ Re-establish RRC connection
  2. Handover
  3. Acquire uplink synchronization
  4. Obtain UL-SCH resources

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. First UL-SCH transmission
   1. Payload depends on use-case 1-4 above
   2. Used for Contention resolution
4. Contention resolution on DL-SCH
   - Echo terminal identity from step 3
   - also other signaling/data

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



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