教育部「5G行動寬頻人才培育跨校教學聯盟計畫」

5G行動網路協定與核網技術聯盟中心

「5G行動寬頻協同網路」課程模組

單元2
LTE-A系統架構

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Outline

- LTE-A Overview
  1. LTE Core Network: EPC
  2. LTE Radio Access Network: E-UTRAN
  3. Connectivity among eNodeBs: The X2 Interface
- E-UTRAN Overview (TS 36.300)
  4. Overall architecture
  5. Physical Layer for E-UTRA
  6. Layer 2
  7. RRC
  19. S1 Interface
  20. X2 Interface
  24. Support for 5GC

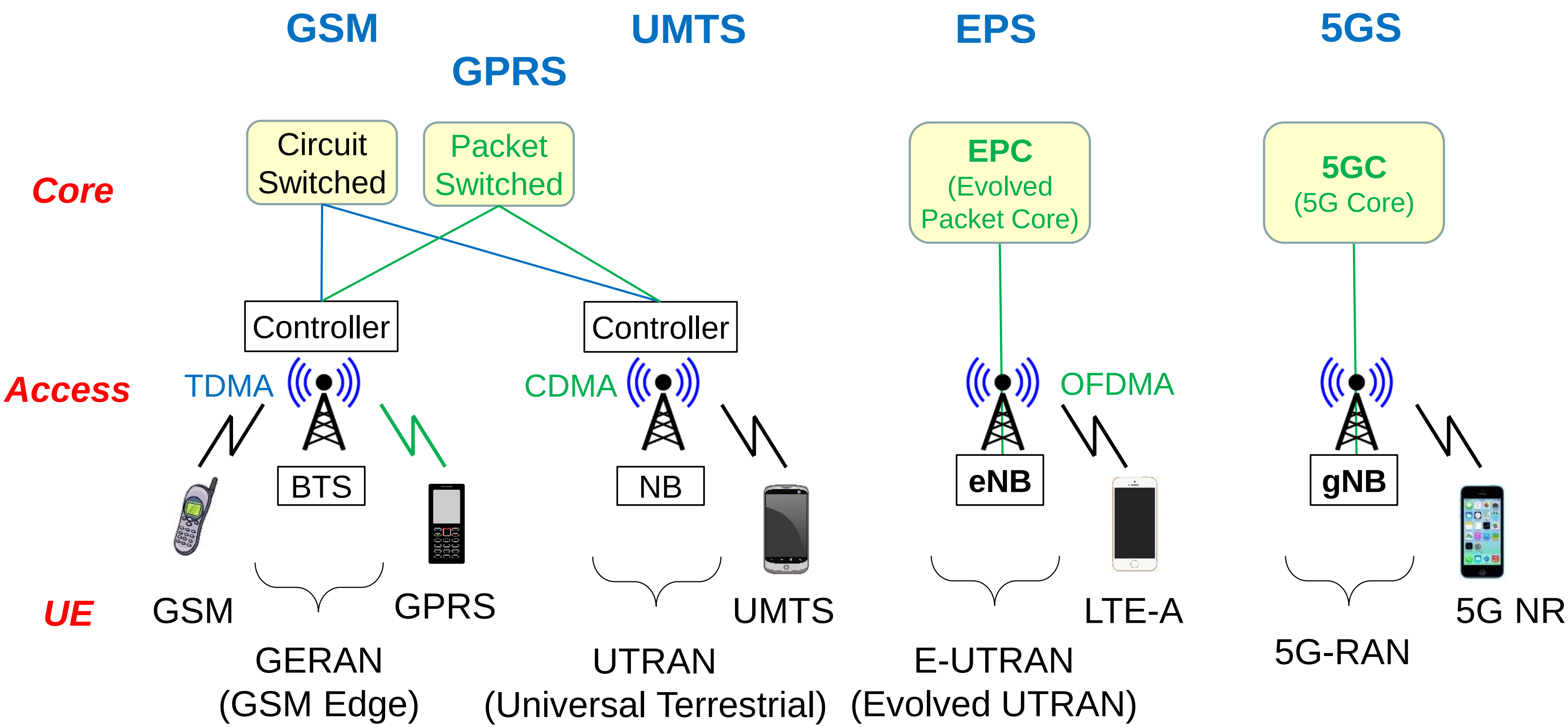
References:

- TS 23.401: GPRS enhancements for E-UTRAN access (EPC)
- TS 24.301: Non-Access-Stratum (NAS) protocol for EPS; Stage 3
- TS 36.300: E-UTRAN Overall description; Stage 2
- Joydeep Acharya, Long Gao, and Sudhanshu Gaur, *Heterogeneous Networks in LTE-Advanced*, John Wiley & Sons, Ltd, 2014

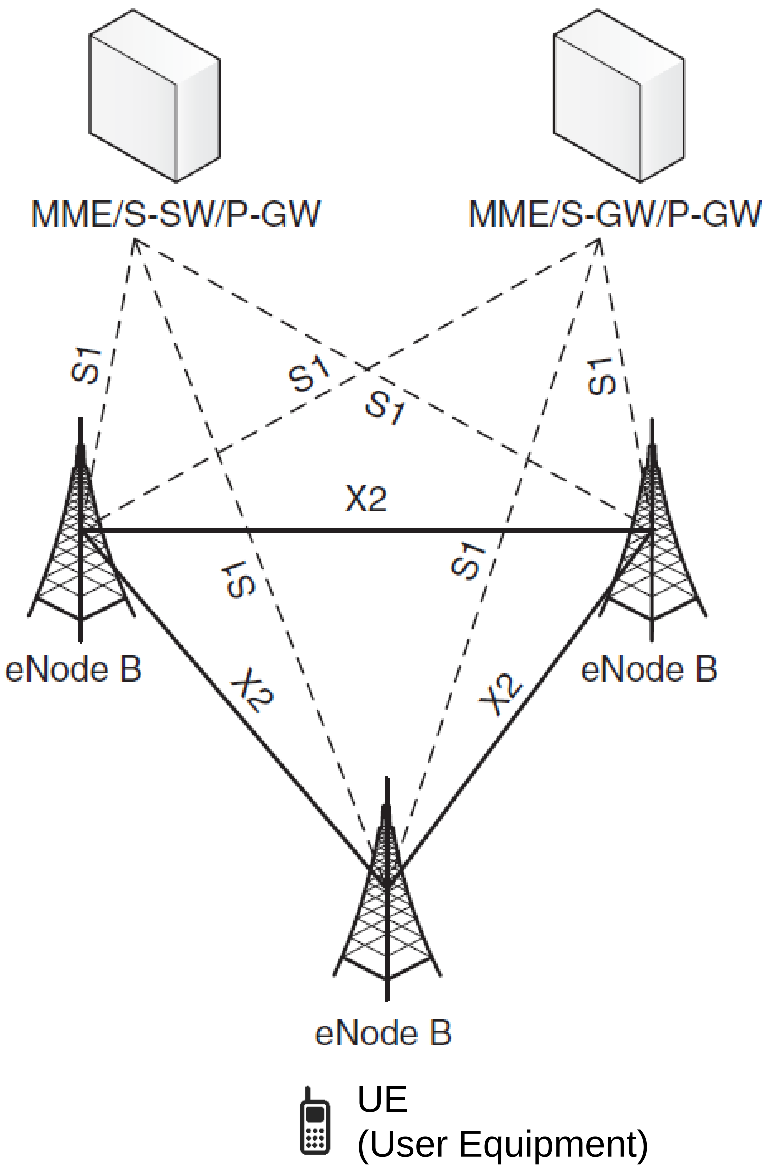
LTE-A Overview

- LTE motivation: moving 3G/UMTS to 4G
  - Need to ensure the continuity of competitiveness of the 3G (UMTS) system for the future
    - Technically
      - User demand for higher data rates and quality of service
      - Packet switch optimized system
      - Low complexity
    - Economically
      - Continued demand for cost reduction
        - »CAPEX - Capital Expenditure
        - »OPEX - Operating Expenditure
  - Avoid unnecessary fragmentation of technologies for paired and unpaired band operation
- Design goal for experience of the end users
  - Higher number of supported users
  - Broader range of applications

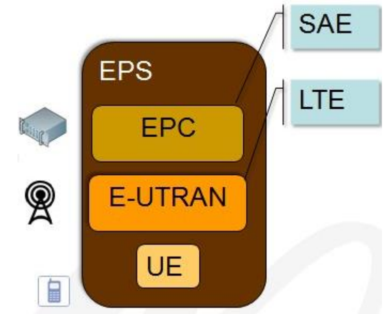
Mobile Networks from GSM to 5G NR



Overall LTE Architecture



EPC (Evolved Packet Core)
– The Core Network (CN)
– The network architecture also called as SAE (Service Architecture Evolution)



E-UTRAN (Evolved Universal Terrestrial Radio Access Network):
– The radio access network to UE
– LTE frequently used to denote LTE E-UTRAN
  - Specifically, the PHY (Physical Layer) and Medium Access Control (MAC) layers

Combination of E-UTRAN and EPC/SAE is also called the Evolved Packet System (EPS)

Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

- E-UTRAN: The first point of entry for a UE to the LTE network
  - Responsible for transmission/reception of radio signals to and from a given UE and the associated digital signal processing

- The E-UTRAN protocols cover the communication process between the UE and the network over the wireless link
  - Include the medium access control mechanisms by which multiple UEs share the common wireless channel
  - Ensure link level reliability, segmentation, and reassembly of higher-layer Protocol Data Units (PDUs) and IP header compression

- enhanced Node B (eNodeB or eNB)
    - The single logical node in the E-UTRAN
    - To implement the AS (Access Stratum) protocols - responsible for transporting data over the wireless connection and managing radio resources

Evolved Packet Core (EPC)

- Purely IP based: a flat, all-IP architecture with separation of control plane and user plane traffic
- When a UE powers on, the EPC is responsible for
  - Authentication and the initial connection establishment needed for all subsequent communication
  - Allocating IP addresses to the UE and forwarding/storing packet data to and from the UE to the external IP network
- In the UMTS and LTE wireless telecom protocol stacks
  - **Access Stratum (AS)** is a functional layer between the *radio* network and UE
  - **Non-Access Stratum (NAS)** is a functional layer between the *core* network and UE
    - The signaling and protocols between the UE and the EPC
- The EPC layer comprises several logical nodes such as
  - Mobility Management Entity (MME)
  - Serving Gateway (S-GW)
  - Public Data Network (PDN) Gateway (P-GW)

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+- - - - - -+          +- - - - - - -+
| HTTP      |          | Application |
+- - - - - -+          +- - - - - - -+
| TCP       |          | Transport   |
+- - - - - -+          +- - - - - - -+
| IP        |          | Internet    |
| -  -   -  |          |  -   -   -  |
| NAS       |          | Network     |
+- - - - - -+          +- - - - - - -+
| AS        |          | Link        |
+- - - - - -+          +- - - - - - -+
| Channels  |          | Physical    |
+- - - - - -+          +- - - - - - -+
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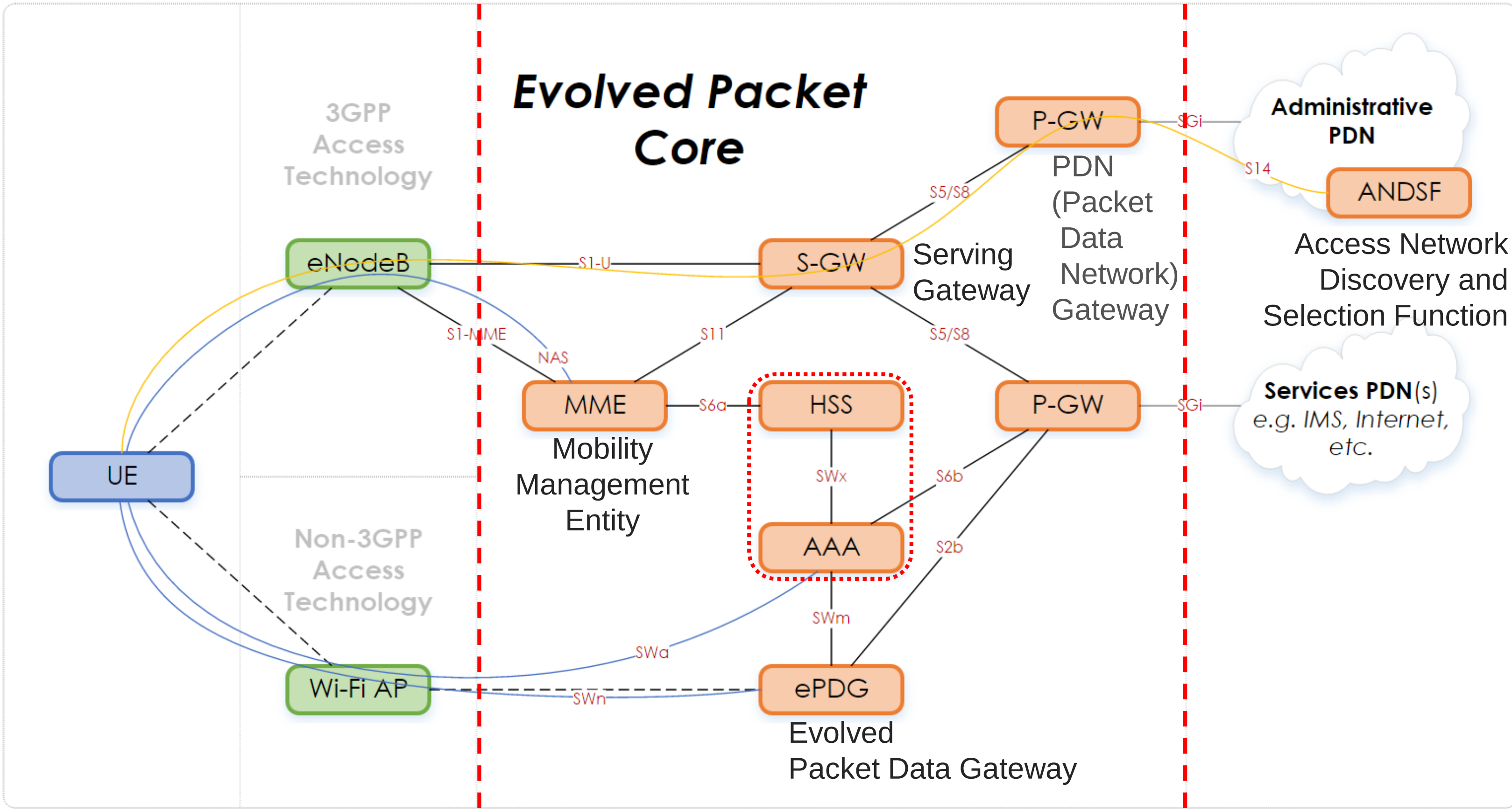
1. LTE Core Network: EPC

LTE: Operates in a connection-oriented mode based on packet mode communications

- Virtual circuit: establishing an end-to-end logical connection before transmitting data
  - The two end entities: between UE and P-GW (Public Data Network Gateway)
- The connection is called the ***EPS Bearer***
  - An EPS bearer is an end-to-end IP packet flow with a defined QoS
    - Many QoS parameters defined in LTE, such as scheduling priority, throughput, and reliability of transmission
  - A UE can be associated with a maximum of 8 EPS bearers, each may differ in
    - Different bearers are associated with different PDN gateways
    - Different bearers are associated with different applications (IMS-based voice/internet data) and thus have different QoS requirements
    - One bearer is the *default bearer* which is set up initially by the network before the UE has started any application, and the other bearers are *dedicated bearers* set up for specific applications

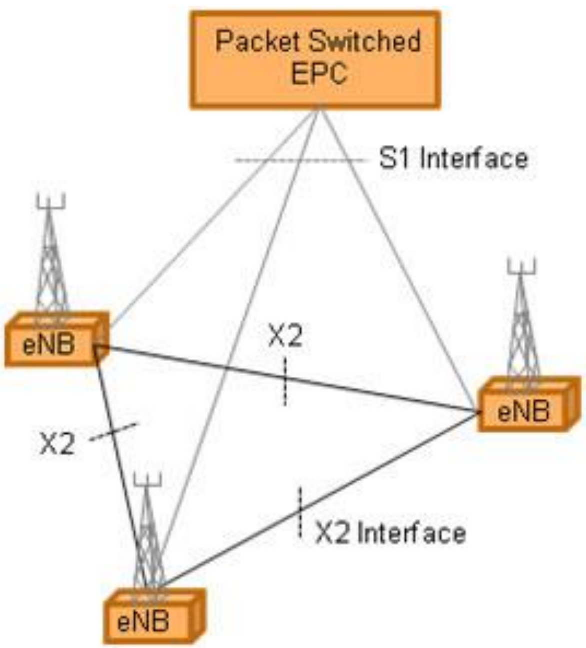
EPS (Evolved Packet System) / SAE

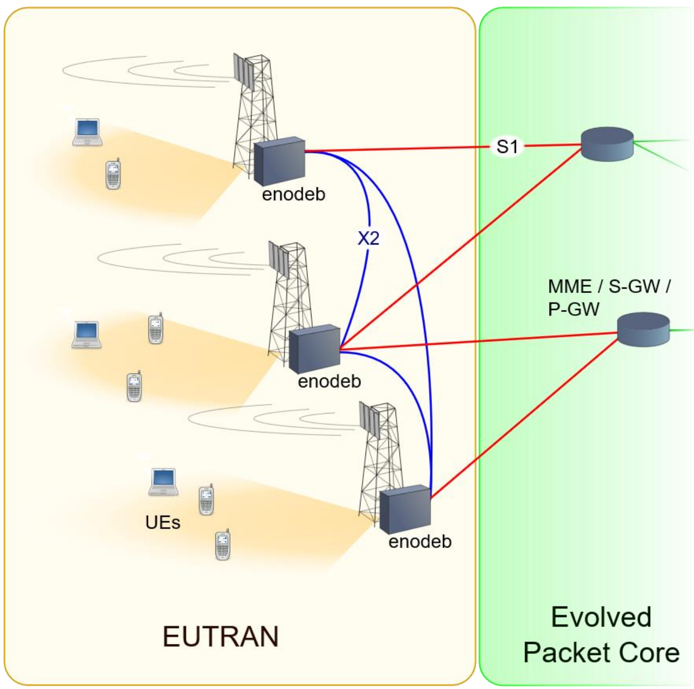


- EPC (Evolved Packet Core): main component of EPS, includes
  - MME: key control-node for LTE – UE paging; chooses S-GW for UE during attach and handover
    - Authenticating the user (by interacting with HSS - Home Subscriber Server)
  - S-GW: manages and stores UE contexts; routes and forwards user data packets
  - P-GW: provides connectivity from the UE to external packet data networks
  - ePDG: secures data transmission with UE connected to EPC over untrusted non-3GPP access
  - ANDSF: provides information to UE to discover available access networks (either 3GPP or not)

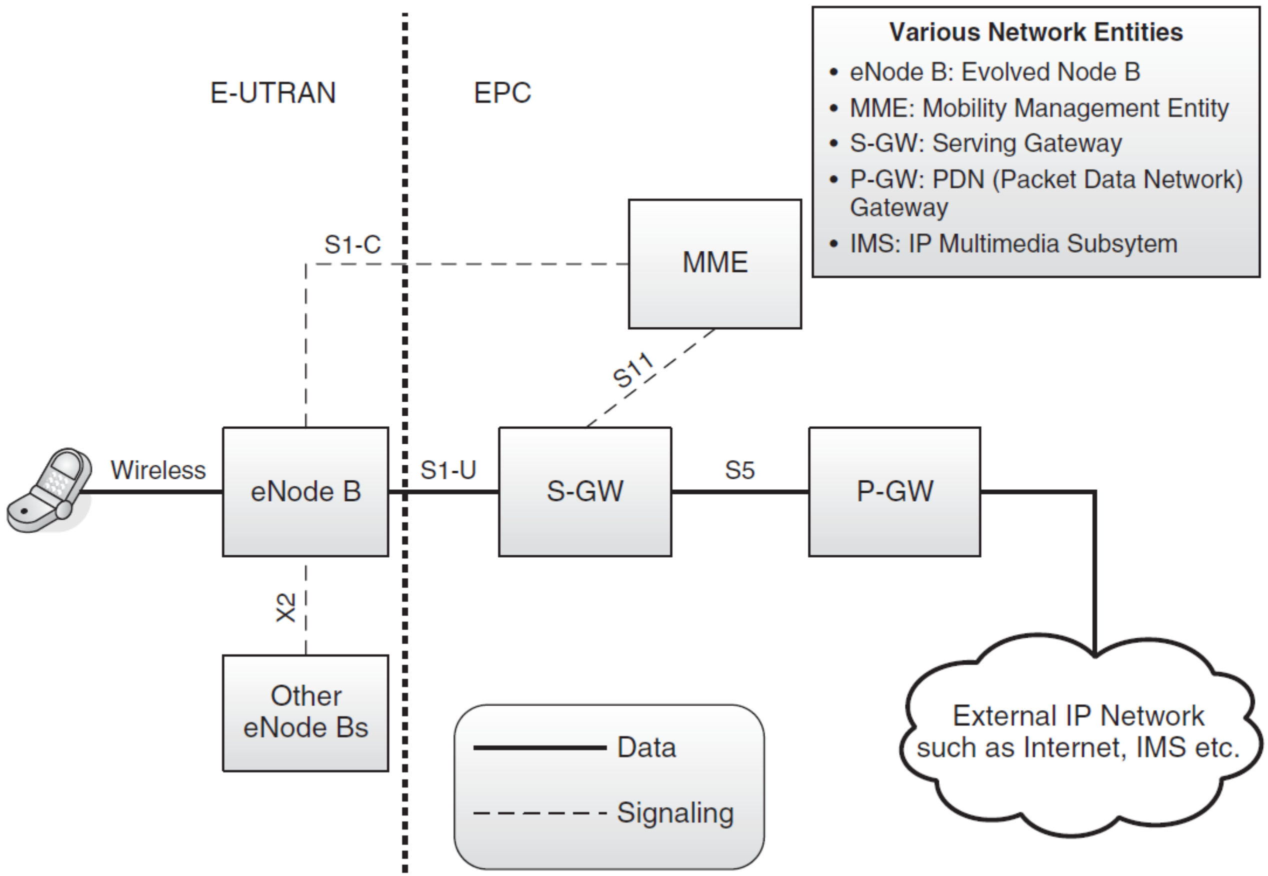
LTE's Distributed Access Network Solution

- Network: a network of base stations, evolved NodeB (eNB)
  - eNBs are normally
    - Inter-connected via the X2-interface and
    - Towards the core network by the S1-interface
  - No centralized intelligent controller: advantages of distributed solution
    - Speed up the connection set-up
    - Reduce the time required for a handover
  - With distributed solution, the MAC protocol layer, which is responsible for scheduling, is represented only in the UE and in the base station leading to fast communication and decisions between the eNB and the UE





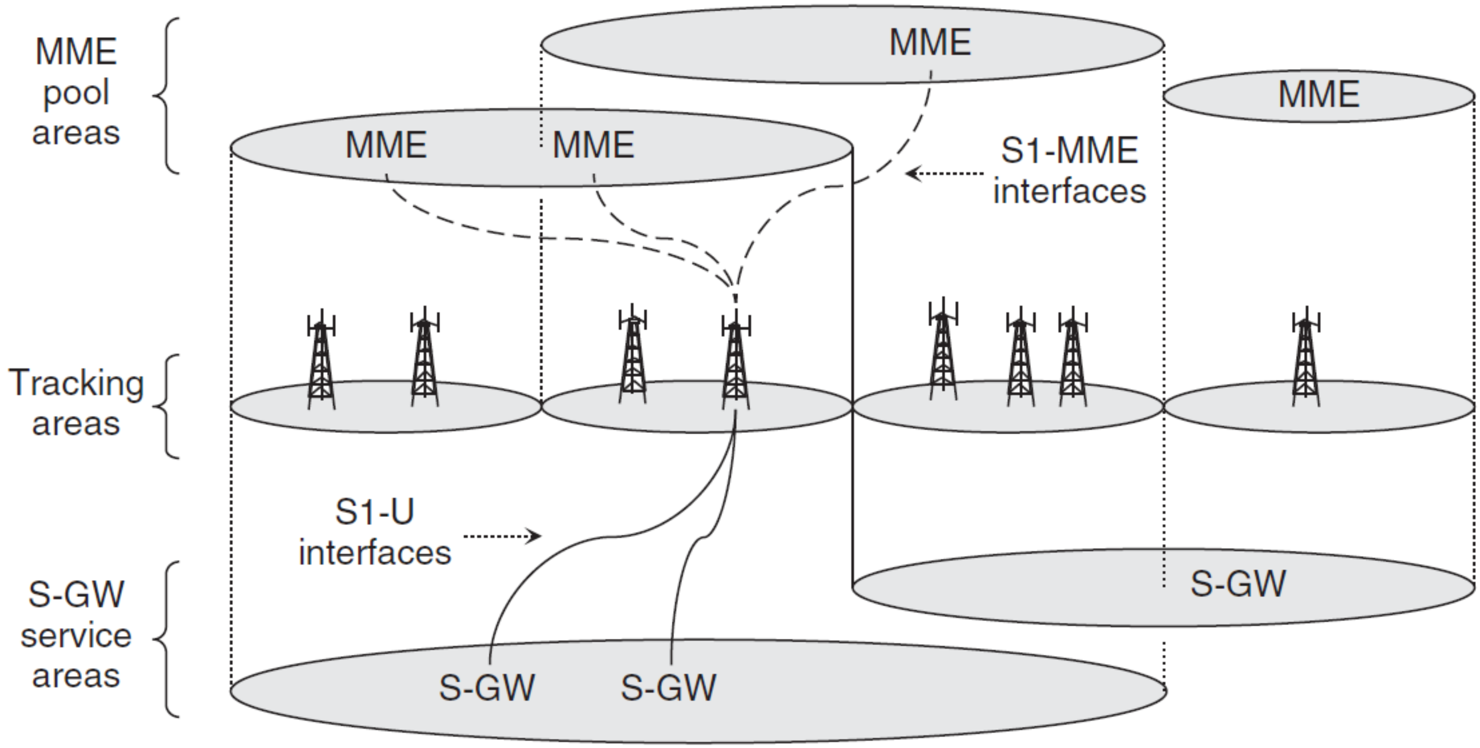
Detailed LTE Architecture



- The Core Network (CN) has a control plane and a user plane
  - Control: MME for NAS signaling between the UE and the CN
  - User: P-GW and S-GW
    - P-GW: default router for UE to an external network
    - S-GW: packet routing and forwarding; mobility anchor for inter-eNodeB handover

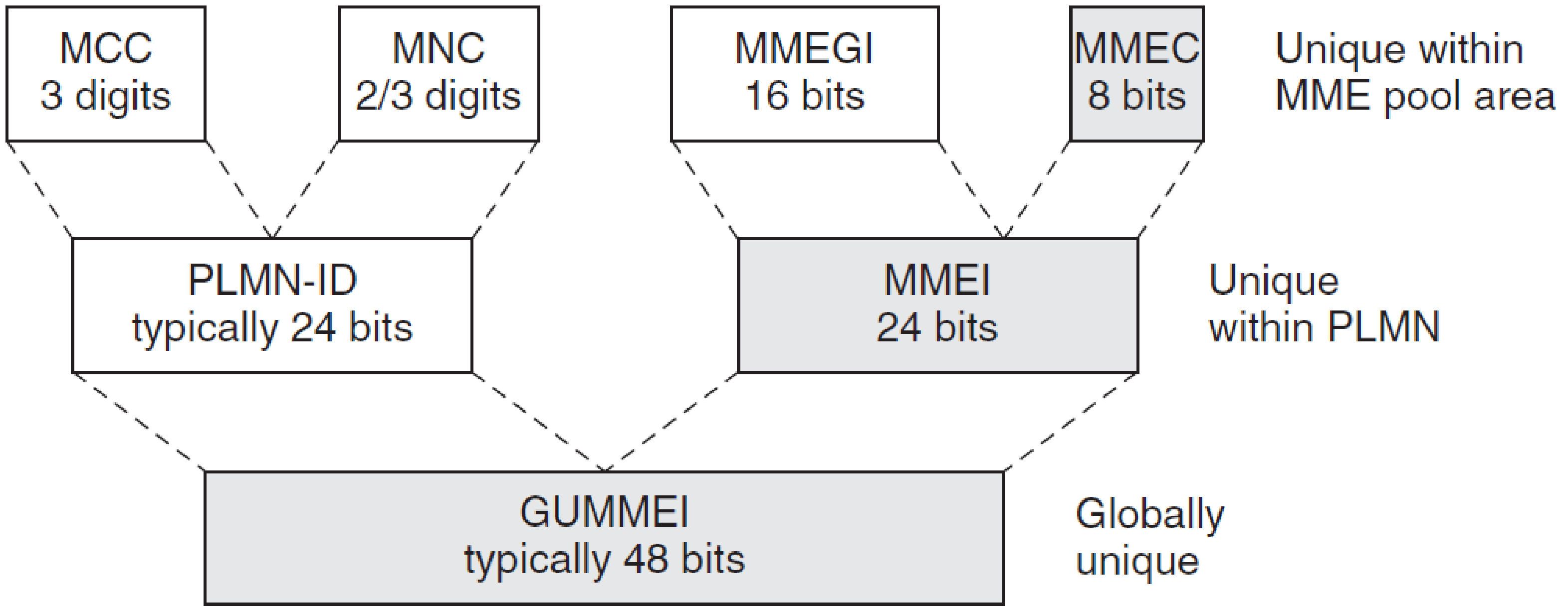
A bearer is from UE to eNodeB to S-GW and finally to P-GW

Three Types of EPC Geographical Areas



- **Tracking area**: smaller, *non-overlapping* units
  – Track the locations of mobiles
- **MME pool area**: an area through which the mobile can move without a change of serving MME
  – A network operator might configure a pool area to cover a large region of the network such as a major city
- **S-GW service area**: an area served by one or more serving gateways, through which the mobile can move without a change of serving gateway

MME Identities



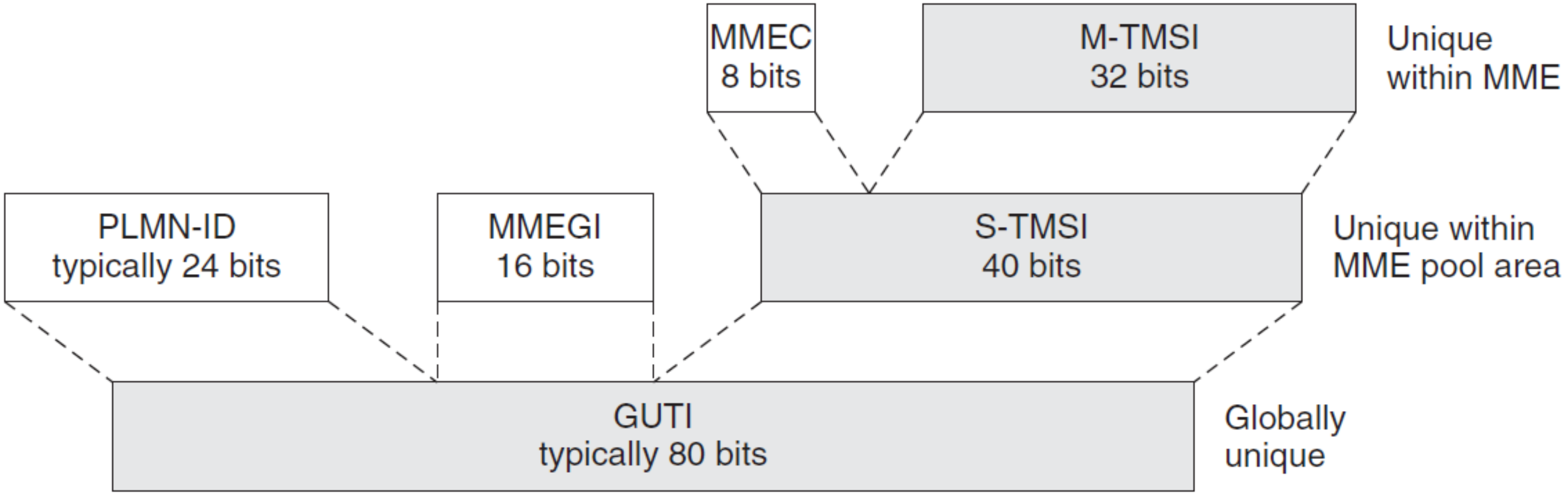
GUMMEI (Global Unique MME Identity) : PLMN-ID + MMEI

- Each network is associated with a PLMN-ID (**Public Land Mobile Network IDentity**)
  - MCC (Mobile Country Code): 234 – UK; 310 – USA; 440 – Japan; 450 – Korea; 460 – China; 466 – Taiwan
  - MNC (Mobile Network Code): 466 01 – FET; 466 92 – CHT; 466 97 – Taiwan Mobile
    - 2 digits for European standard and 3 digits for North American standard
- MMEI (MME Identity)
  - MMEGI (MME Group Identity)
  - MMEC (MME Code)

Identities of Tracking Areas and Cells

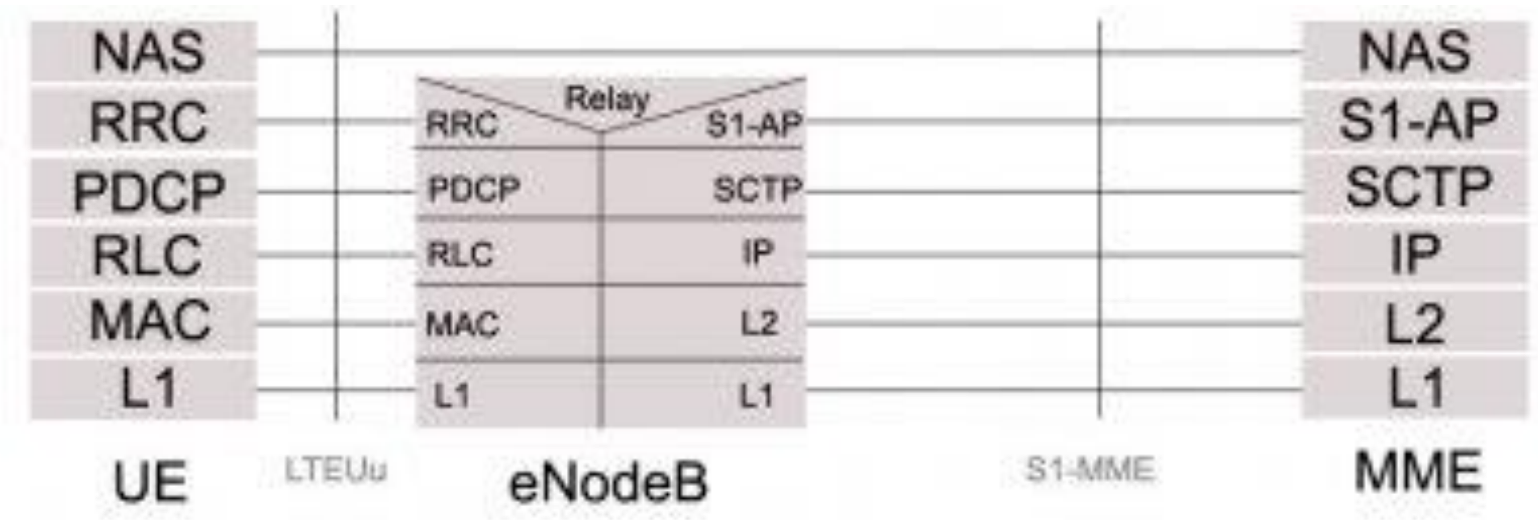
- Each tracking area has two main identities
  - 16-bit TAC (Tracking Area Code) within a particular network
  - TAI (Tracking Area Identity) – globally unique
    - Combining TAC with the network identity (PLMN-ID)
- Each cell has three types of identity
  - 28-bit ECI (E-UTRAN Cell Identity) within a particular network
  - ECGI (E-UTRAN Cell Global Identifier) - identifies a cell anywhere in the world
    - PLMN-ID + ECI
  - PCI (Physical Cell Identity) distinguishes a cell from its immediate neighbors
    - 0 to 503

Identities of UE



- **IMEI (International Mobile Equipment Identity)**: a unique identity for the mobile equipment
- **IMSI (International Mobile Subscriber Identity)**: a unique identity for the UICC and the USIM
  - UICC (Universal Integrated Circuit Card): hardware part of GSM's SIM for UMTS
  - USIM (Universal Subscriber Identity Module)
  - 64-bit/15-digit: 3-digit MCC + 2/3-digit MNC (PLMN ID) + remaining MSIN
    - MSIN (Mobile Subscription Identification Number): within the network's customer database
- Temporary identities updated at regular intervals
  - A serving MME identifies each mobile using temporary identities to avoid transmitting IMSI across the air
  - 32-bit **M-TMSI (M Temporary Mobile Subscriber Identity)**: identifies a mobile to its serving MME
    - *Randomly assigned* to every mobile in the area
    - The identity that is most commonly sent between the mobile and the network
  - 40-bit S-TMSI (S Temporary Mobile Subscriber Identity): identifies the mobile within an MME pool area
    - 8-bit MMEC + 32-bit M-TMSI

Non-Access Stratum (NAS)



- The highest stratum of the control plane
  - Convey non-radio signalling between UE and MME
- The NAS procedures are grouped in two categories:
  - the EPS **Mobility** Management (EMM) → Mobility Management Function (MMF)
  - the EPS **Session** Management (ESM) → Session Management Function (SMF)

https://www.3gpp.org/technologies/keywords-acronyms/96-nas

EPS Mobility Management (EMM)

- Refers to procedures related to mobility over an E-UTRAN access, authentication and security
  - It is the equivalent in EPS of MMF in 5GS, MM in GSM and GMM in GPRS

- 3GPP specifications make distinction among three kinds of procedures
  - EMM common procedures
  - EMM specific procedures
  - EMM connection management procedures

EMM Common Procedures

- EMM common procedures refer to various network-initiated mechanisms
  - GUTI (Global Unique Temporary ID) reallocation
  - Authentication
  - Security mode control
  - Identification
  - EMM information

EMM Specific Procedures

- EMM specific procedures are UE-initiated
  - Define attach/detach (to/from the EPC) mechanisms

- EPS Introduces the **Tracking Area Update (TAU)** mechanism
  - **Tracking Area** is the equivalent in EPS of Location Area in GSM and Routing Area in GPRS
  - Update the location of the UE within the network
  - In EPS, a UE initiates a Tracking Area Update when it detects that it enters into a new Tracking Area
  - EMM specific procedures also define periodic Tracking Area Update

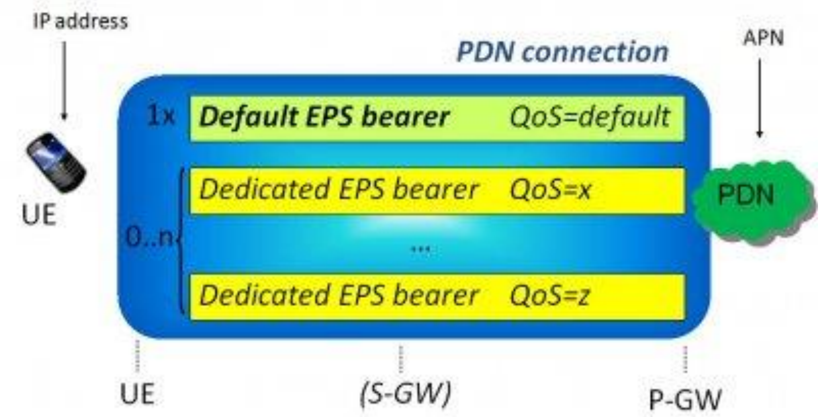
- EPS also introduces the concept of **Tracking Area List (TAL)**, which allows the provision of lists of Tracking Areas in UEs
  - A UE does not need to initiate a TAU if it enters a Tracking Area which is included in its TAL
  - Provisioning different lists to the UEs within the network avoid signalling peaks for instance when all UEs on a train cross a TA border

EMM Connection Management (ECM) Procedures

- EMM connection management procedures provide several functions to support the connection of the UE to the network
  - ***Service request***: initiated by the UE to start the establishment of NAS signalling connection
  - ***Paging***: initiated by the network in case of downlink NAS signalling to indicate to the UE to start a service request
  - ***Transport of NAS messages***: used for SMS (CS fallback)
  - Generic transport of NAS messages: Various other applications (e.g. LCS)

EPS Session Management (ESM)

- The EPS Session Management protocol offers support to the establishment and handling of user data in the NAS
  - Two concepts are introduced to define the IP connectivity between a UE and a **packet data network (PDN)**: PDN connection and EPS bearer



- A ***PDN connection*** is composed of a *default EPS bearer* and possibly additional ones called "*dedicated bearers*"
  - Within a PDN connection, all EPS bearers share a same UE IP address and an APN
  - A *default bearer* is created upon establishment of a PDN connection
  - If a service (e.g. video streaming) requires specific handling in terms of quality of service (QoS), *dedicated bearers* can be established

- EPS supports multiple simultaneous PDN connections
  - For instance, a UE can have a PDN connection to the Internet (with just a default EPS bearer) and one to the operator's IMS (with additional dedicated bearers, if required by the service)

ESM Procedures

ESM procedures are grouped into two categories

- **EPS bearer procedures**, which are network-initiated and provide mechanisms for
  - Activation, deactivation or modification of EPS bearers
- **Transaction-related procedures**, which are UE-initiated and provide mechanisms for:
  - Requests for PDN connection establishment and disconnection
  - Requests for bearer resources allocation and modification
  - Release requests

CN Control Plane

- The main entity in the control plane is the Mobility Management Entity (MME)
- The MME is responsible for
  - NAS signaling between the UE and the CN
    - Takes place when a UE initially powers on and then attaches itself to the LTE network
  - The establishment, maintenance, and release of the EPS bearers
  - Keeping track of the UEs when they are in idle mode
  - Managing interconnection between LTE and other 2G-/3G-based cellular networks

CN User Plane

- Two main logical entities in the user plane: P-GW and S-GW
  - Packet Gateway (P-GW): connecting a UE to an external packet data network (PDN) such as the internet and IMS (IP Multimedia Subsystem)
    - Acts as the default router for the UE and is responsible for IP address allocation for the UE
    - Performs flow control and QoS enforcement of the IP packet flow to the UE
  - Serving Gateway (S-GW): responsible for overall packet routing and forwarding to and from the UE
    - In case of inter-eNodeB handovers, the S-GW acts as the local mobility anchor
    - If the UE is in idle mode and data comes for the UE from the external network, the S-GW buffers the data packets and requests the MME to page the UE

- An EPS bearer is a data connection from the UE to the eNodeB to the S-GW and finally to the P-GW
  - A UE can have multiple IP addresses corresponding to connections with different P-GWs (different PDNs with multiple bearers)
  - It is managed by the MME but does not contain it, as no data transfer takes place through the MME

Practical Implementations of the Core Network

- MME, S-GW and P-GW are logical entities

- Possible implementation options to integrate logical entities
  - MME and S-GW combined, and P-GW is separate
    - Allows for easier interoperability between LTE and a 3G network (with similar design)
  - S-GW and P-GW (of user plane) are combined, MME (of control plane) is separate
    - S-GW and P-GW are essentially IP packet routers with evolved functionalities
  - All three separate - the most flexible design

- Tradeoffs
  - Integrating more logical entities in a physical node will normally reduce latency and delay as the internode signaling is reduced
  - Complexity of an individual physical node increases

Process of Assigning Logical Entities to a UE

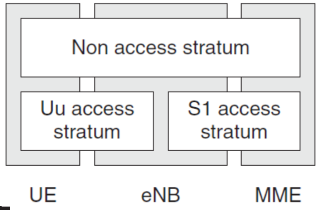
Establishing a bearer from UE to eNodeB to S-GW and finally to P-GW

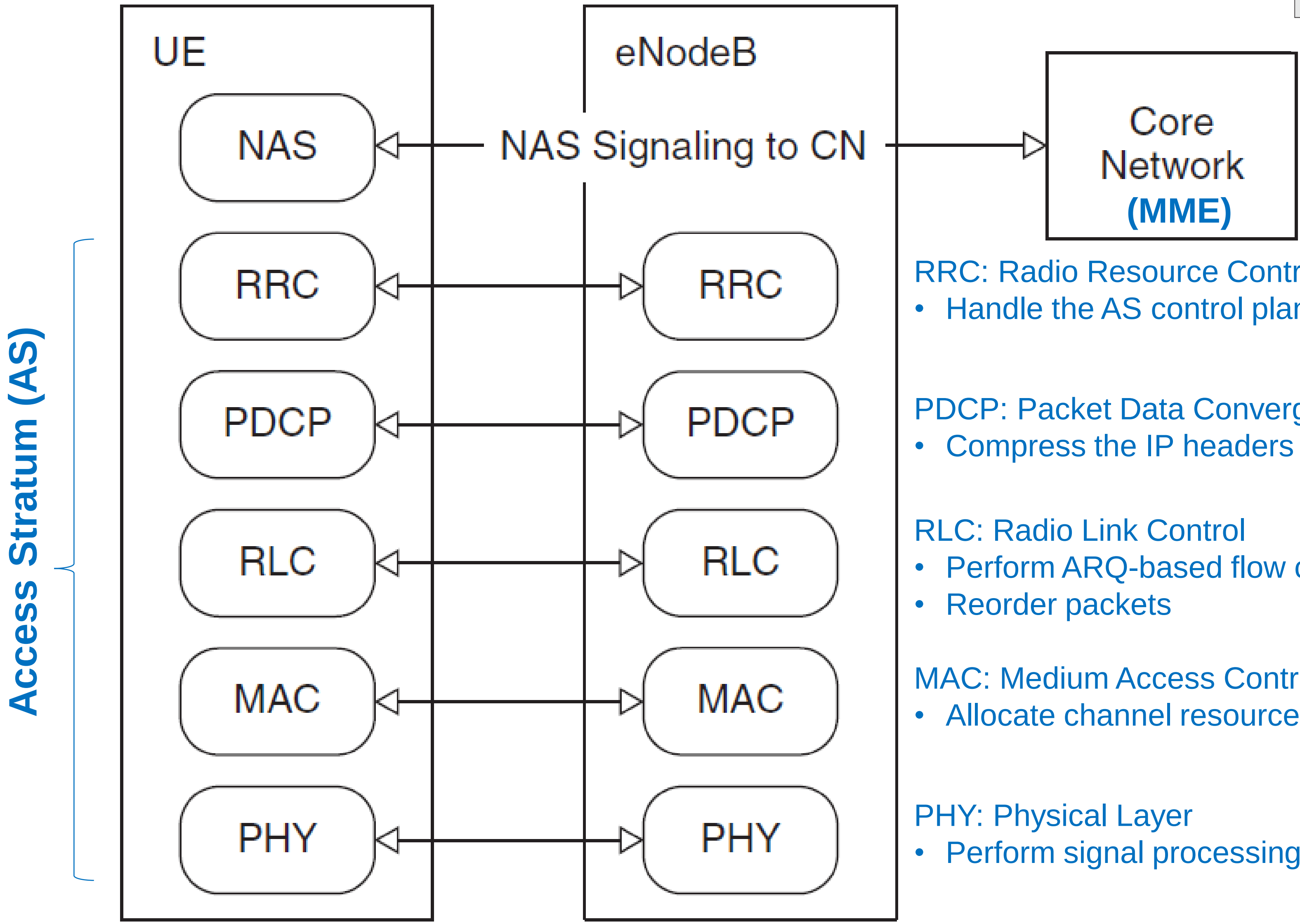
1. The UE selects the eNodeB
   - Based on received signal strength measurements
2. The eNodeB selects the MME
   - Based on load-balancing algorithms that ensure that the CN signaling load in a MME does not become too high
   - Or choosing the previous MME that the UE was connected to
3. The MME selects the S-GW
   - Based on geographical location of the UE
   - Picking up a S-GW that serves the eNodeB to which the UE is associated
   - Load-balancing algorithms are used to choose between multiple S-GWs
4. The UE chooses a Packet Data Network (PDN) such as the internet based on the application it wishes to run
   - An **Access Point Name (APN)** is a gateway between a GSM, GPRS, 3G or 4G mobile network and another computer network, frequently the public Internet
   - The APN identifies the (PDN) that a mobile data user wants to communicate with
   - Usually auto-configured, sometimes need to manual input the APN data
5. The MME chooses a P-GW for the UE based on the PDN

2. LTE Radio Access Network: E-UTRAN

- E-UTRAN
  - Responsible for radio access of the UE to the LTE network
  - Implemented by a single node, the eNodeB
- Important functionalities of eNodeB
  - Signals transmitted wirelessly suffer attenuations in amplitude and phase
    - The E-UTRAN therefore performs sophisticated **Physical Layer (PHY)** signal processing to ensure a reliable reception
  - The wireless channel is of limited bandwidth and is a broadcast medium. When multiple UEs access the channel simultaneously, they interfere with each other
    - The E-UTRAN therefore performs **Radio Resource Management (RRM)** and **Medium Access Control (MAC)** functionalities to allocate the channel resources among the various users in a fair manner
  - The errors introduced by the wireless channel cannot be totally corrected by the PHY and MAC/RRM functionalities
    - An **Automatic Repeat Request (ARQ)** based flow control is required between the eNodeB and the UE. It is performed by the **Radio Link Control (RLC)** layer
  - The IP header overhead is large
    - The **Packet Data Convergence Protocol (PDCP)** compresses the IP headers from higher layers so that they are suitable for transmission over the wireless channel
  - **Radio Resource Control (RRC)** layer handles the control plane functionalities
    - Configuring the connection, measurement report, reconfiguration (handover), etc

E-UTRAN Control Plane Protocols





RRC: Radio Resource Control
- Handle the AS control plane; Configure

PDCP: Packet Data Convergence Protocol
- Compress the IP headers

RLC: Radio Link Control
- Perform ARQ-based flow control
- Reorder packets

MAC: Medium Access Control
- Allocate channel resources; Scheduler

PHY: Physical Layer
- Perform signal processing

Two RRC States : RRC_IDLE or RRC_CONNECTED

- UE is in either of the two RRC states
  - RRC_IDLE: performs only the most important control signaling
    - Works in partial sleep mode to save the battery life
    - Monitors the paging channel periodically to see if there are any incoming calls for it; if so, it switches to the RRC_CONNECTED mode
  - RRC_CONNECTED: The UE is more closely controlled
    - Needs to perform more tasks and thus reduces the battery life
    - It’s capable of complete data transmission and reception
- The UE therefore periodically switches to the RRC_IDLE state, where it is in partial sleep mode

RRC IDLE State

- When a UE powers on, it is initially in the RRC_IDLE state
  - The UE has to first decide which eNodeB to associate with for subsequent control and data communications
  - This is called **cell selection** or deciding a cell to **camp on**

- Cell selection process:
  1. Initial Cell Detection
     - When a UE powers on, it searches sequences in the received radio signal to find pre-stored/known eNodeBs
  2. Received Signal Strength Measurement
     - The UE then measures certain signals from available eNodeBs to determine the eNodeB with the best downlink gains
  3. Reading of System Information
     - The UE now reads the System Information Blocks (SIBs) which contain control signal from both AS (generated at RRC level) and NAS (generated by the CN)
  4. Final Association
     - The UE can further check if the received signal strength is over a certain threshold in order to finalize the association

Step 1. Initial Cell Detection

- LTE is an asynchronous network
  - Different eNodeBs transmit with their own symbol and frame timings
  - A UE has to first synchronize with it
- In LTE each eNodeB has a unique *physical layer* cell ID (0 to 503)
  - Each eNodeB periodically transmits two signals for synchronization and computing cell ID (N_{CID}= 3*N_{GID} + N_{PID})
    - Primary Synchronization Signal (PSS): carries physical layer identity (N_{PID} = 0,1,2)
    - Secondary Synchronization Signal (SSS):carries physical layer cell identity group(N_{GID}=0 to 167)
- Correlation process: when a UE powers on
  - It searches for PSS/SSS sequences in the radio signal that it receives by correlating the received signal with the known PSS/SSS sequences
    - A list of cell IDs and PSS/SSS sequences for all eNodeBs are stored in each UE
    - The correlation process therefore not only gives the UE the cell IDs of the eNodeBs in the vicinity, but also their symbol timings
  - Then it decodes the Physical Broadcast Channel (PBCH) to obtain **Master Information Block (MIB)** (24 bits) broadcasted by the eNodeB (40 ms periodically)
    - The MIB contains important system information to completely decode control channels later
    - 3-bit: system bandwidth (1.4, 3, 5, 10, 15, 20 MHz)
    - 3-bit: Physical Hybrid-ARQ Indicator Channel (PHICH，transmission mode and # of transmitting antennae)
    - 8-bit: system frame number keep changing

Step 2. Received Signal Strength Measurement

- The UE then measures certain signals called ***Reference Signals (RS)*** from each eNodeB to determine the eNodeB with the best downlink gains
  - A LTE signal can be centered around multiple carrier frequencies
  - In LTE, a UE measures RSSI (Received Signal Strength Indicator), RSRP (Reference Signal Received Power) and RSRQ (Reference Signal Received Quality)

- A UE can be programmed a priori by the service provider so that there are some *preferred* carriers defined

- The UE maintains a list of the eNodeBs with strongest link gains for each *allowed carrier* in which it can subsequently transmit and receive data

Step 3. Reading of System Information

- The UE now reads the **System Information Blocks (SIBs)** which contain control signal from both AS (generated at RRC level) and NAS (generated by the CN)
  - These SIBs are carried in the **Physical Downlink Shared Channel (PDSCH)**

- Specifically, the UE decodes SIB-1 which provides information about the **public land mobile network (PLMN)** identity of the eNodeB
  - The UE checks if it is permitted to associate with a eNodeB with the decoded PLMN identity

- If it is not permitted (e.g. the UE might have been trying to camp on to an eNodeB that belongs to a different operator), it goes back to the list of eNodeBs and chooses the eNodeB with the next strongest link
  - It then repeats step 3

Step 4. Final Association

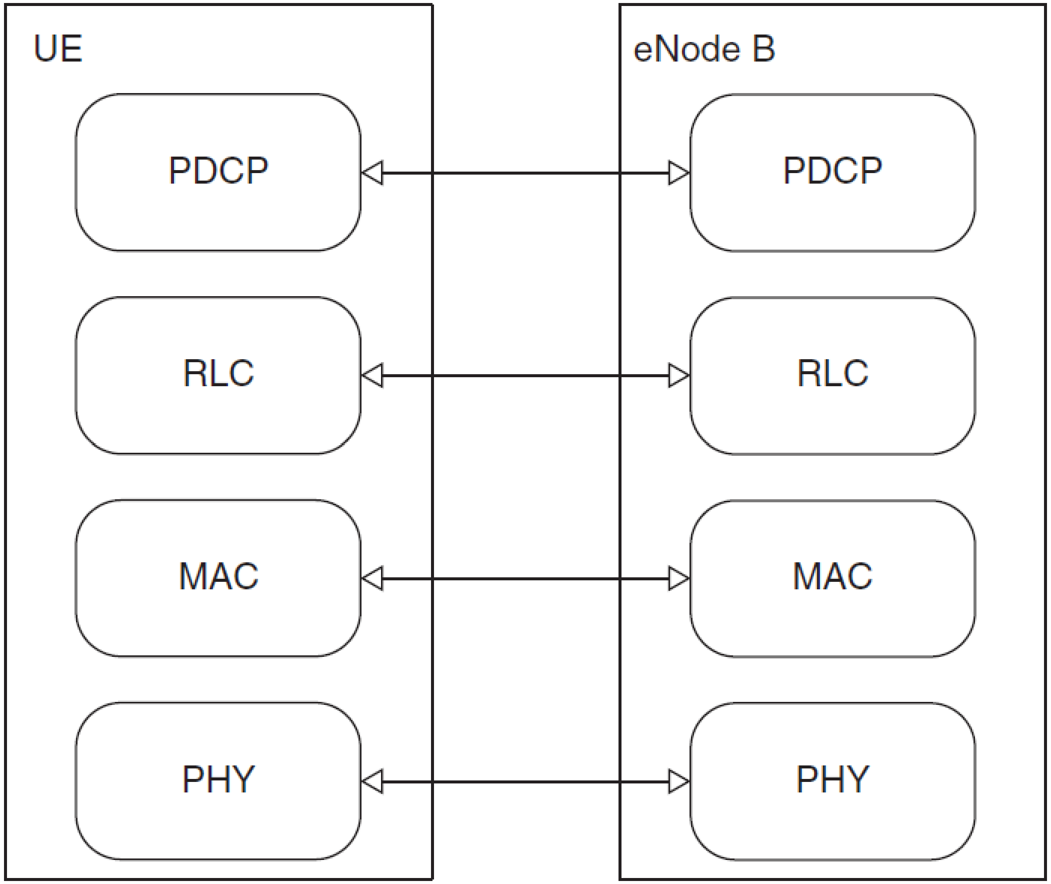
- Check if the received signal strength is over a certain threshold in order to finalize the association
- Once the UE has camped on a cell, it continues to monitor the other neighboring eNodeBs
  - A RRC_IDLE UE can undergo ***cell reselection*** if it detects a eNodeB with stronger link gain
  - The radio link quality is the most important criterion for cell selection and reselection, but not the only criterion
    - Since the radio link is however time varying: there could be a ping-pong effect where the UE switches connection between a group of eNodeBs continuously
    - There are therefore other criterion such as eNodeB priorities, especially for cell reselection
- The threshold mentioned in this step could be adjusted once a UE performs initial cell selection, in order to prevent it from frequent reselection

RRC CONNECTED State

- In the RRC_CONNECTED state, from the E-UTRAN the UE can
  - Monitor an associated control channel, the **Physical Downlink Control Channel (PDCCH)**
  - Receive data via the **Physical Downlink Shared Channel (PDSCH)**
  - Transmit data from the corresponding **Physical Uplink Shared Channel (PUSCH)**
  - Provide channel quality and feedback information to the eNodeB

- In the connected mode, the UE can change cell associations as it did in idle mode
  - In the connected mode, however, this is initiated and managed by the network and is called **handover**
  - Similar to cell reselection, handover is based primarily on link qualities but includes other parameters

E-UTRAN User Plane Protocols



PDCP: Packet Data Convergence Protocol
- Compress the IP headers

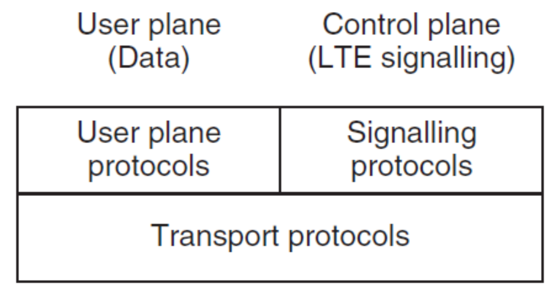
RLC: Radio Link Control
- Recode/segment-and-reassembly

MAC: Medium Access Control
- Multiplexing of data

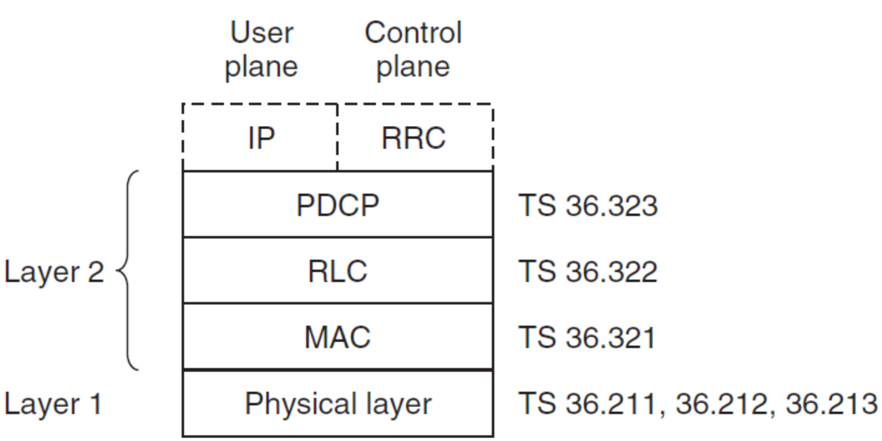
PHY: Physical Layer
- Radio signal transmission and reception
- OFDM
- AMC (adaptive modulation and channel coding)

Protocol Models of CN and RN

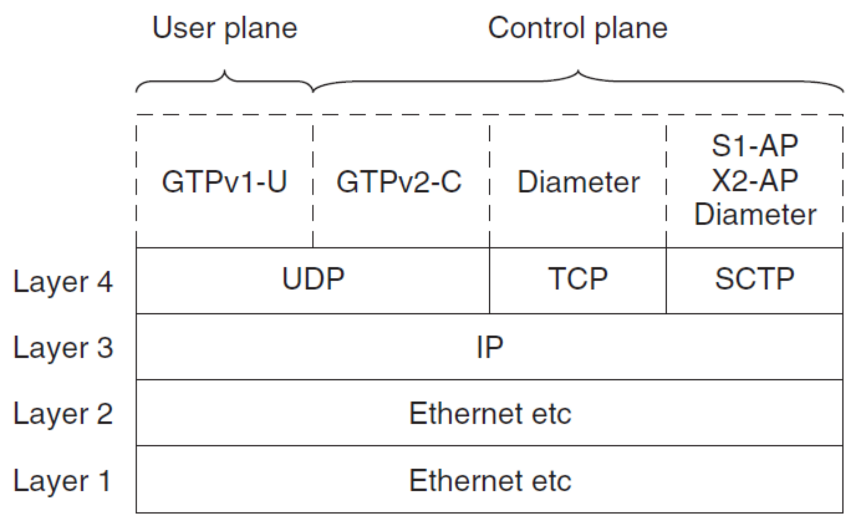
- Two main layers
  - Upper layer: manipulate information specific to LTE
  - Lower layer: transport information from one point to another
- Three types of protocols
  - (Control plane) signaling protocols
  - User plane protocols
  - Transport protocols: transfer data and signaling messages



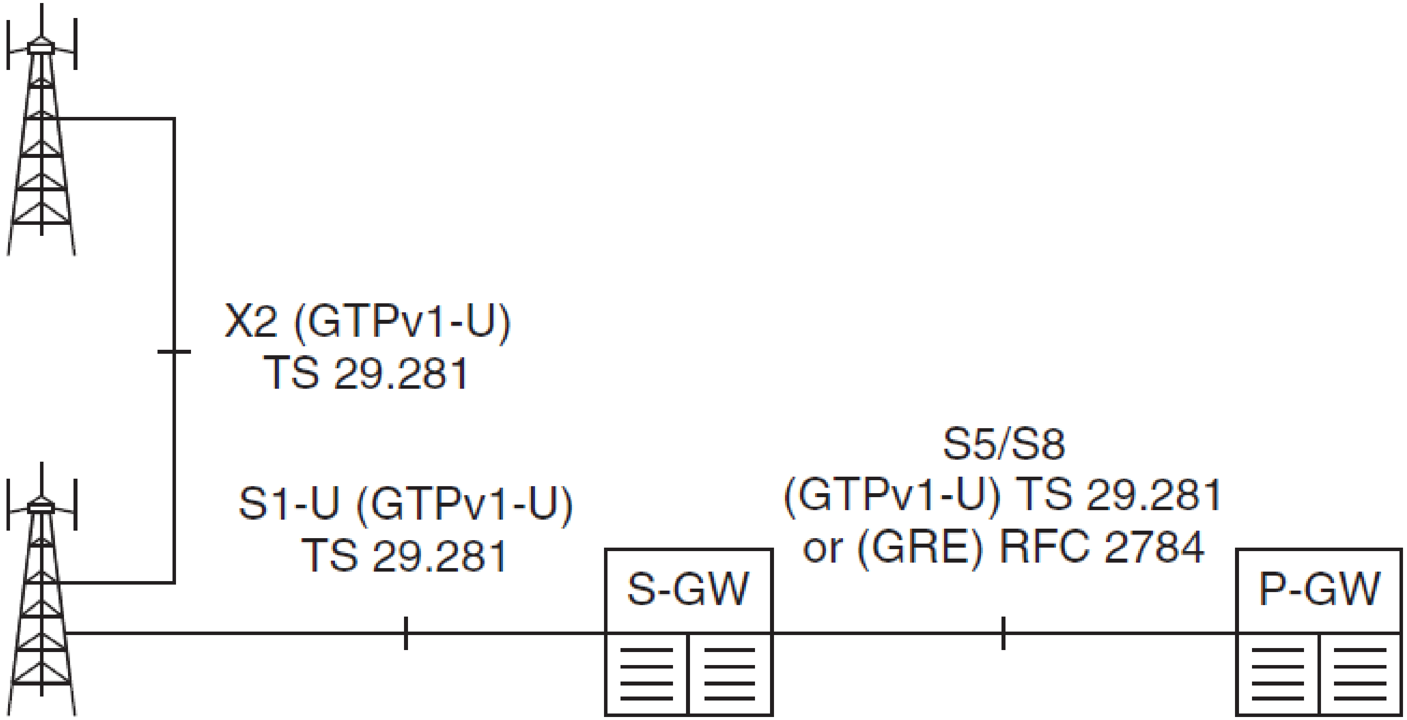
On the air interface



By the fixed network

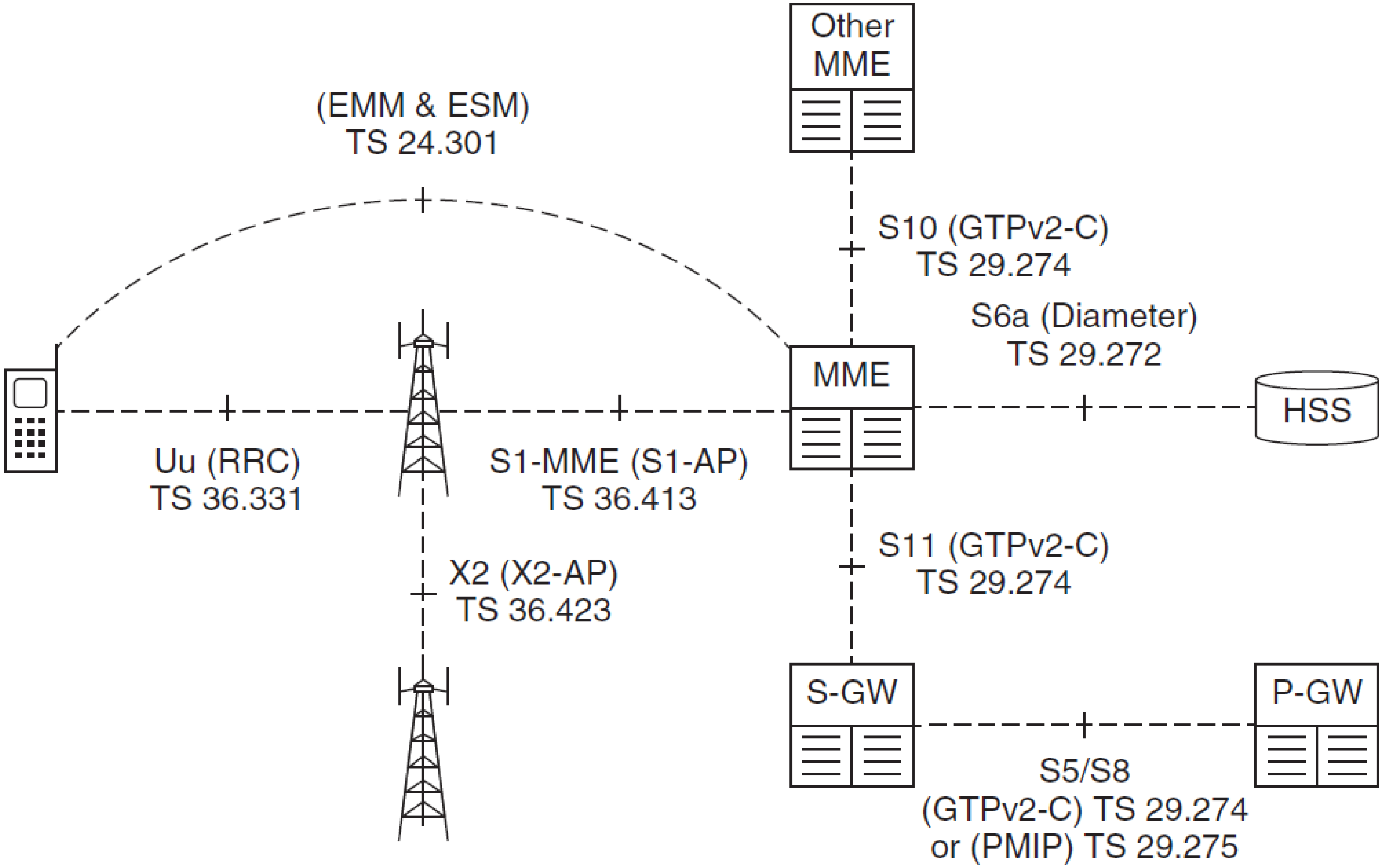


User Plane Protocols



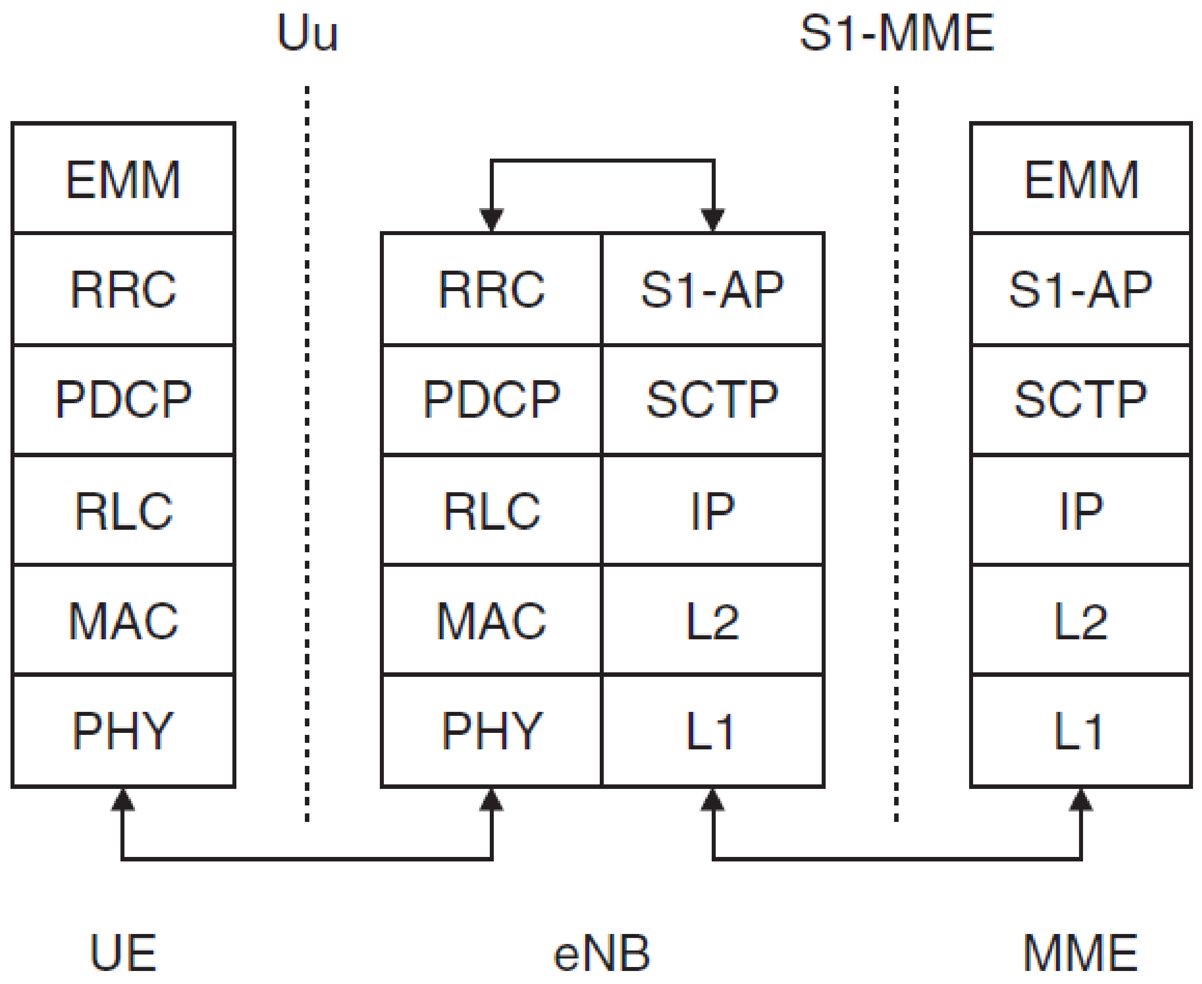
- GTP-U (GPRS Tunneling Protocol – User part)
  - LTE uses version 1 (GTPv1-U) along with 2G and 3G from release 99
- S5/S8 alternative: IETF GRE (Generic Routing Encapsulation)

Control Plane Signaling Protocols



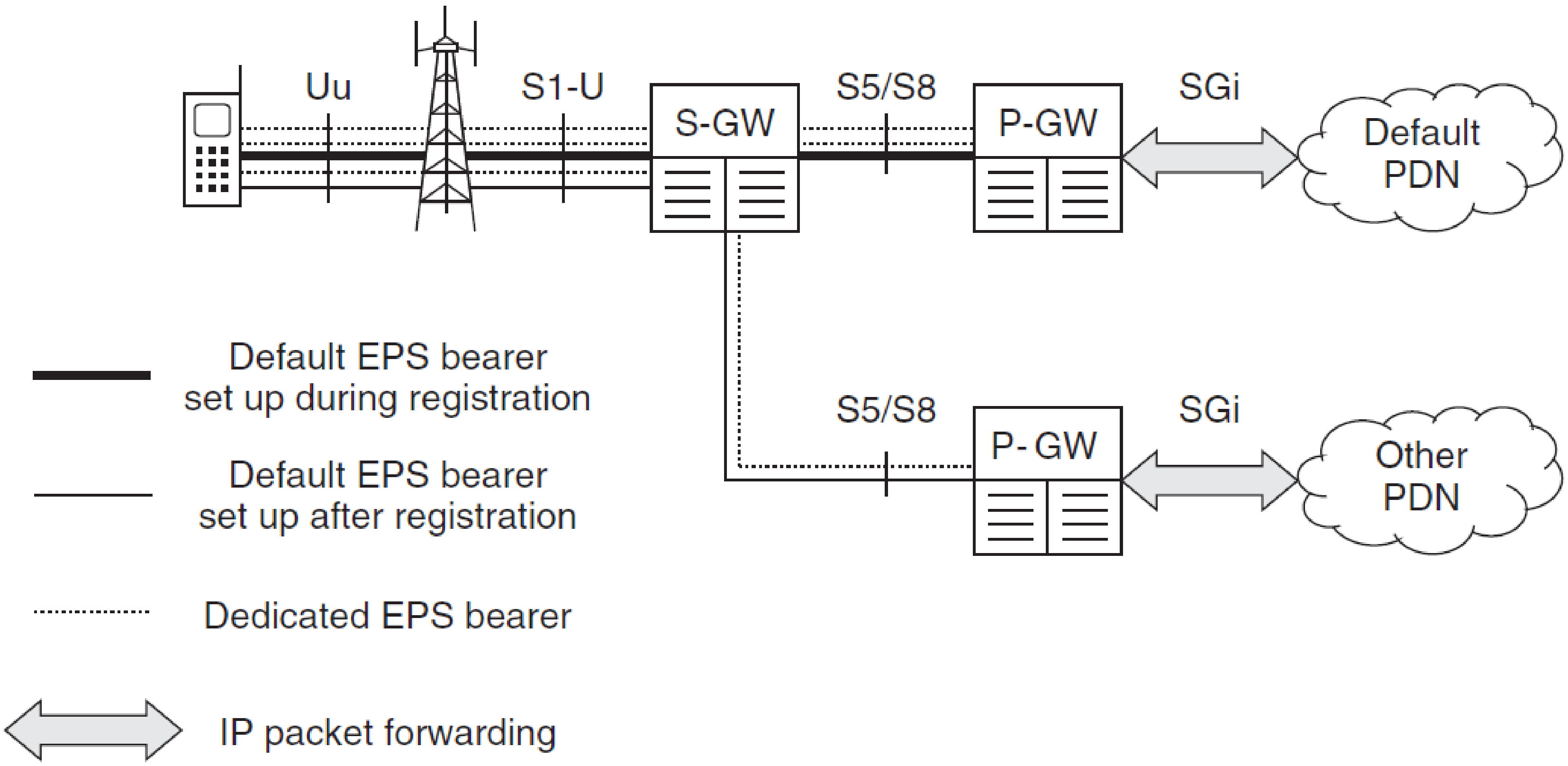
- EMM (EPS Mobility Management)
- ESM (EPS Session Management)
- X2-AP (X2 Application Protocol)
- PMIPv6 (Proxy Mobile IPv6)

Protocol Stack to Exchange NAS Signaling



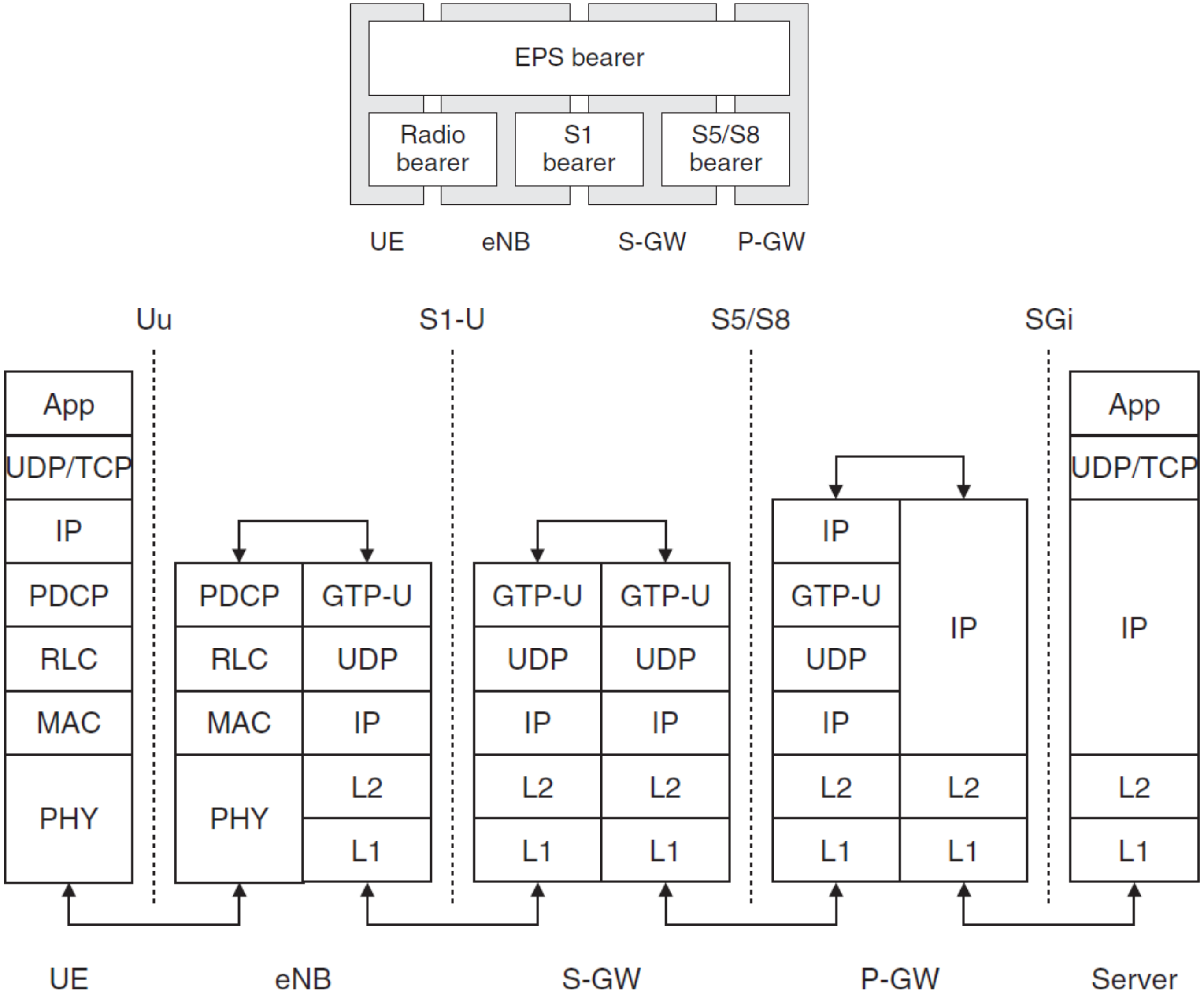
TS 23.401

Default and Dedicated EPS Bearers



Bearer using S5/S8 interface based on GTP

Bearer Implementation Using GTP



TS 23.401

3. Connectivity among eNodeBs: The X2 Interface

- The X2 interface which connects two eNodeBs to allow them to communicate and share information
  - It allows two eNodeBs such as a macrocell and a picocell to 'talk' to each other and thus implement many of the advanced interference coordination algorithms
- The X2 interface
  - A point-to-point logical interface between two eNodeBs
  - Usually implemented over an actual physical connection between the two eNodeBs

Latency and throughput of some commonly used mediums for backhaul

Medium	Latency (one way, round trip, ms)	Throughput (average, Mbps)
Fiber	5–10	100–1000
Cable	25–35	10–100
DSL	15–60	10–100
Wireless	5–35	10–100

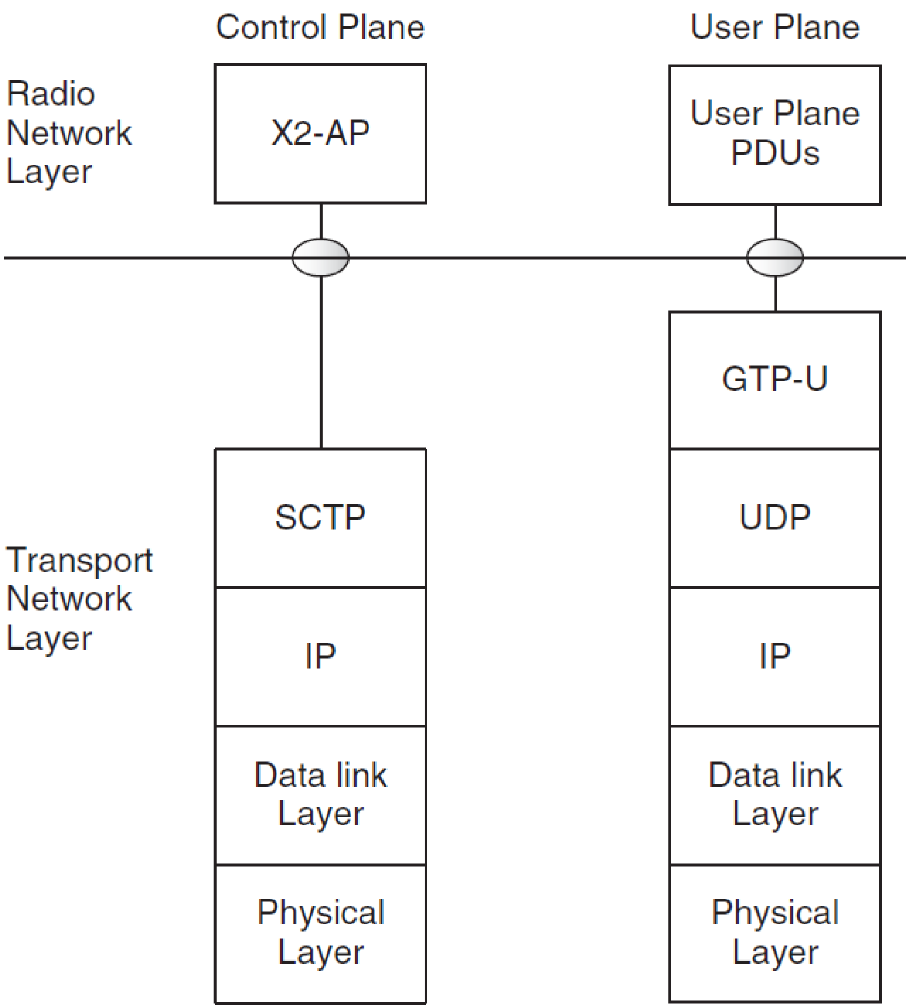
  - It is also possible that there is no direct physical connectivity between the eNodeBs
    - Realized as the eNodeBs are connected via the EPC (e.g. two eNodeBs may be served by the same MME)

Discovery of Neighboring eNodeBs

- A LTE eNodeB can identify and authenticate a neighboring eNodeB
  - Manually: configured manually by the operator who set up the network
    - This process is cumbersome and unreliable, especially when new eNodeBs are dynamically deployed in the network
  - Automatically: **Automatic Neighbor Relation Function (ANRF)** performs smart neighbor discovery
    - All eNodeBs broadcast information such as cell identities that a UE in their coverage area can measure during the cell association process
    - After association, an eNodeB can ask its UEs to report these measurements and use them for neighbor discovery
    - ANRF is an example of a broader class of LTE functionalities called SON (Self-organized Network) which were introduced for automatic self-configuration and operation of the LTE network

- Once the neighboring cells have been identified, a eNodeB triggers the **X2 setup procedure**
  - This involves the initiating eNodeB sending a X2_SETUP_REQUEST message and the receiving eNodeB replying with an acknowledgement

Protocols for X2 Signaling Bearer and Data Stream Transmission



Two planes of X2

- Control Plane: exchange signaling message
- User Plane: exchange PDUs (Protocol Data Unit)

Example: X2-based Handover

- The control plane first carries signaling messages that are required to set up the handover procedure
  - SCTP to ensure higher reliability
- The user plane then transfers the user data from the source eNodeB to the target eNodeB
  - UDP to be faster but less reliable

Two types of information may be exchanged over X2

- Load- and Interference Related Information
- Handover-Related Information

SCTP (Stream Control Transmission Protocol) :
Reliable, message-based, multi-streaming/Multi-homing

X2: Load- and Interference-Related Information

- Load balancing: distribute UE traffic load uniformly among eNodeBs
  - In UMTS, the RNC took care of load management between the base stations that were connected to it
  - In LTE, the eNodeBs themselves exchange this information via the X2 interface
    - Exchange usage pattern of their bandwidth to convey load-related information
      - For example, what percentage of their allocated bandwidth is being used by real-time vs non-real-time traffic
    - Jointly perform load management by optimizing cell reselection and handover parameters for
      - Current UEs that are already associated, or
      - New UEs who may request service in the future

- Interference indication messages
  - *Reactive:* Separate indication messages are exchanged between neighboring eNodeBs to denote the real-time interference being faced by an eNodeB from a neighboring eNodeB
  - *Proactive:* An eNodeB can also indicate to a neighboring eNodeB if it is planning to increase traffic which would cause interference to its neighbor
    - Such messages are available for both downlink and uplink interference scenarios

X2: Handover-Related Information

- UE Handover between two eNodeBs
  - Indirectly via the CN
  - Directly between two eNodeBs by signaling over X2
    - The MME is informed only after successful completion of the handover
    - The source eNodeB chooses the handover mode based on the Quality of Service (QoS) requirements of the associated EPS bearer
- X2-based handover
  - Initialized by the source eNodeB by sending a HO_REQUEST message to the target eNodeB
  - Upon receiving the request message, the target eNodeB
    - Allocates resources needed for the handover and
    - Then responds with a HO_REQUEST_ACK message
  - In the subsequent handover process, UE PDUs are transferred from the source to the target eNodeB along with other UE information via the User Plane of X2
    - User PDU transfer can either be seamless, which minimizes the time taken by the handover process, or lossless, which maximizes the reliability of the user data

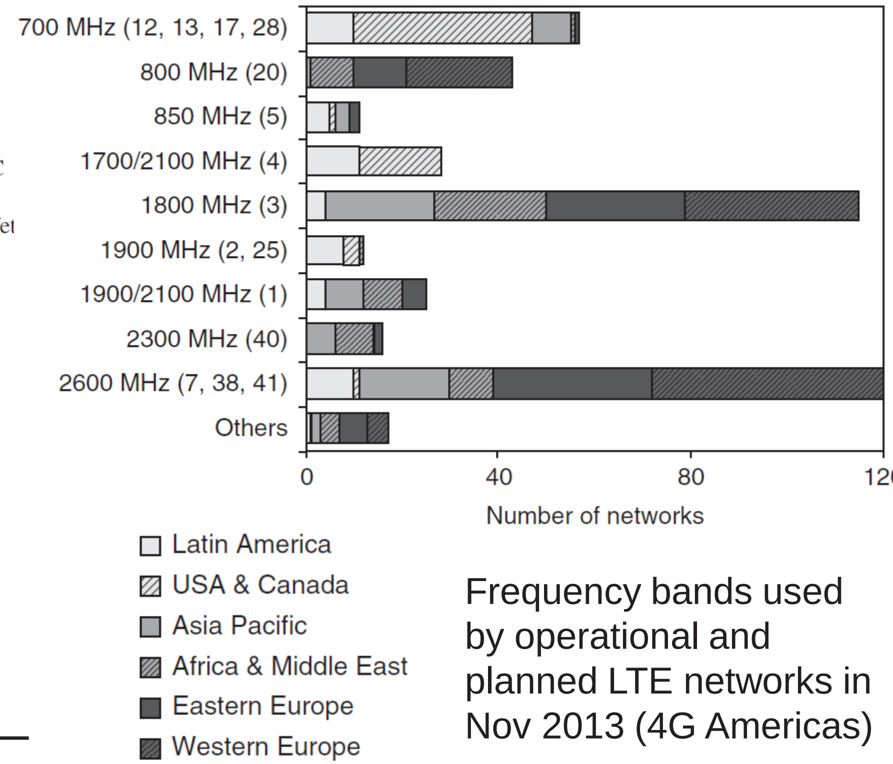
Frequency Bands

FDD

Band	Release	Uplink band (MHz)	Downlink band (MHz)	Main regions	Common name	Notes
1	R99	1920–1980	2110–2170	1, 3	2100	WCDMA
2	R99	1850–1910	1930–1990	2	1900	PCS
3	R5	1710–1785	1805–1880	1, 3	1800	GSM 1800
4	R6	1710–1755	2110–2155	2	1700/2100	AWS
5	R6	824–849	869–894	2, 3	850	GSM 850
6	–	–	–			Not used by LTE
7	R7	2500–2570	2620–2690	1, 2, 3	2600	
8	R7	880–915	925–960	1, 3	900	GSM 900
9	R7	1749.9–1784.9	1844.9–1879.9	Japan		
10	R7	1710–1770	2110–2170	2		AWS extension
11	R8	1427.9–1447.9	1475.9–1495.9	Japan	1500	
12	R8	699–716	729–746	USA	700	Lower band A, B, C
13	R8	777–787	746–756	USA	700	Upper band C
14	R8	788–798	758–768	USA	700	Upper D, public safet
15	–	–	–			Not used by 3GPP
16	–	–	–			Not used by 3GPP
17	R8	704–716	734–746	USA	700	Lower band B, C
18	R9	815–830	860–875	Japan		
19	R9	830–845	875–890	Japan		
20	R9	832–862	791–821	Europe	800	Digital dividend
21	R9	1447.9–1462.9	1495.9–1510.9	Japan	1500	
22	R10	3410–3490	3510–3590	1, 2, 3		
23	R10	2000–2020	2180–2200	USA		S band
24	R10	1626.5–1660.5	1525–1559	USA		L band
25	R10	1850–1915	1930–1995	2	1900	PCS extension
26	R11	814–849	859–894	2, 3		Bands 5, 18, 19
27	R11	807–824	852–869	2		
28	R11	703–748	758–803	3	700	Digital dividend
29	R11	–	717–728	USA		Carrier aggregation
30	R12	2305–2315	2350–2360	USA		WCS
31	R12	452.5–457.5	462.5–467.5	1, 2, 3	450	

TDD

Band	Release	Frequency band (MHz)	Main regions	Common name	Notes
33	R99	1900–1920	1, 3		
34	R99	2010–2025	3		
35	R99	1850–1910	2		PCS
36	R99	1930–1990	2		PCS
37	R99	1910–1930	2		PCS
38	R7	2570–2620	1, 2, 3	2600	
39	R8	1880–1920	China		
40	R8	2300–2400	3	2300	
41	R10	2496–2690	USA	2600	
42	R10	3400–3600	1, 2, 3		
43	R10	3600–3800	1, 2, 3		
44	R11	703–803	3		



Frequency bands used by operational and planned LTE networks in Nov 2013 (4G Americas)

- Region 1: Europe, Africa and North West Asia
- Region 2: Americas
- Region 3: South East Asia (including India and China) and Australasia

LTE Frequency Bands Operated in Taiwan

頻段	類型	中華	台哥大	遠傳	亞太	台灣之星
700MHz	4G		A4 (Band 28) 733~748MHz 788~803MHz	A2 (Band 28) 713~723MHz 768~778MHz	A1 (Band 28) 703~713MHz 758~768MHz A3 (Band 28) 723~733MHz 778~788MHz	
900MHz	4G	B2 (Band 8) 895~905MHz 940~950MHz			B3 (Band 8) 905~915MHz 950~960Mhz	B1 (Band 8) 885~895MHz 930~940MHz
1800MHz	4G	C2 (Band 3) 1725~1735MHz 1820~1830MHz C5 (Band 3) 1755~1770MHz 1850~1865MHz	C1 (Band 3) 1710~1725MHz 1805~1820MHz	C3 (Band 3) 1735~1745MHz 1830~1840MHz C4 (Band 3) 1745~1755MHz 1840~1850MHz		
2600MHz	4G	D2 (Band 7) 2520~2540MHz 2640~2660MHz D4 (Band 7) 2560~2570MHz 2680~2690MHz		D3 (Band 7) 2540~2560MHz 2660~2680MHz D6 (Band 41) 2595~2620MHz	D5 (Band 38) 2570~2595MHz	D1 (Band 7) 2500~2520MHz 2620~2640MHz

2015.12.10(修訂)--http://blog.dg-space.com

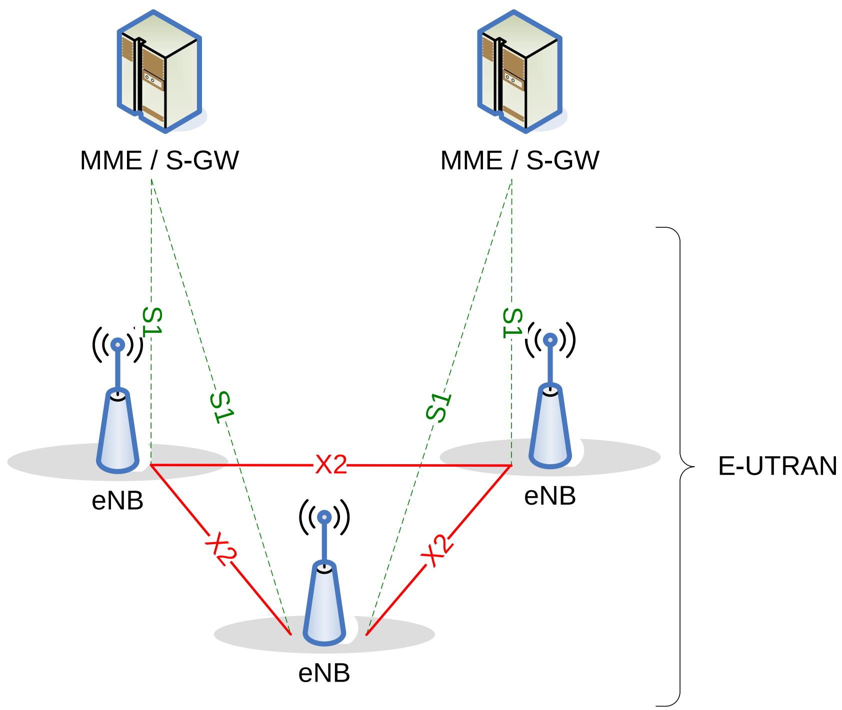
Outline

- LTE Overview
  1. LTE Core Network: EPC
  2. LTE Radio Access Network: E-UTRAN
  3. Connectivity among eNodeBs: The X2 Interface
- E-UTRAN Overview (TS 36.300)
  4. Overall architecture
  5. Physical Layer for E-UTRA
  6. Layer 2
  7. RRC

  19. S1 Interface
  20. X2 Interface
  24. Support for 5GC

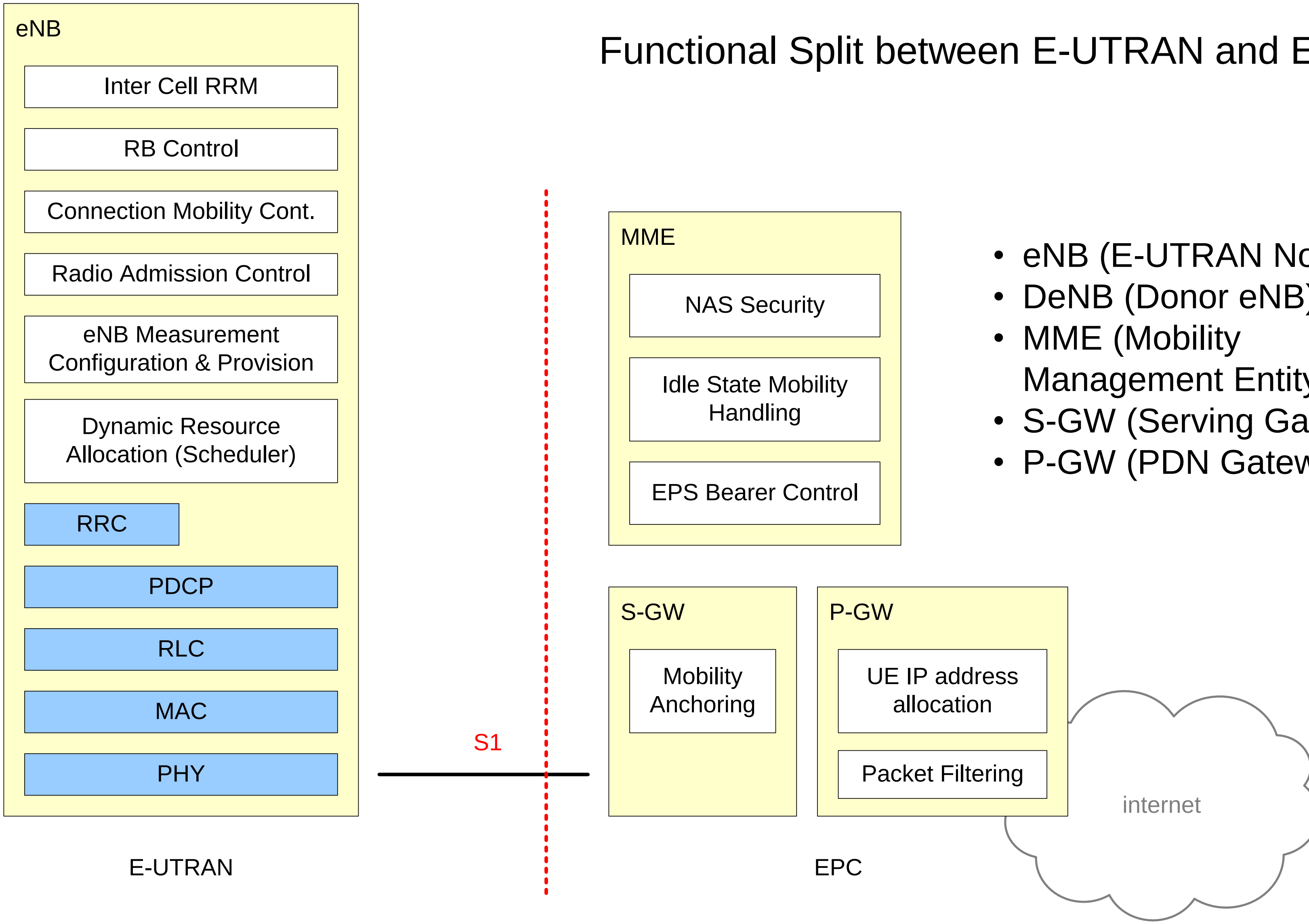
4. E-UTRAN Overall Architecture

- 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 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 interface and
  - to the Serving Gateway (S-GW) by means of the S1-U interface



4.1 Functional Split

Functional Split between E-UTRAN and EPC



- eNB (E-UTRAN Node B)
- DeNB (Donor eNB)
- MME (Mobility Management Entity)
- S-GW (Serving Gateway)
- P-GW (PDN Gateway)

Functions of eNB

- Functions for Radio Resource Management
  - Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in uplink, downlink and sidelink (scheduling)
- IP header compression, uplink data decompression 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 MME or O&M)
- Measurement and measurement reporting configuration for mobility and scheduling
- Scheduling and transmission of PWS (which includes ETWS and CMAS) messages (originated from the MME)
- CSG handling (Closed Subscriber Group)
- Transport level packet marking in the uplink
- S-GW relocation without UE mobility (TS 23.401)
- SIPTO@LN handling (Selected IP Traffic Offload at the Local Network)
- Maintaining security and radio configuration for User Plane CIoT (Cellular Internet of Things) EPS optimizations (TS 24.301)
- Optionally registering with the X2 GW (if used)

Functions of DeNB

The DeNB hosts the following functions in addition to the eNB functions

- S1/X2 proxy functionality for supporting RNs (Relay Node)
- S11 termination and S-GW/P-GW functionality for supporting RNs

Functions of MME (TS 23.401)

- NAS signalling
- NAS signalling security
- AS Security control
- Selection of CIoT EPS optimizations
  - (e.g., Control Plane CIoT EPS optimization, as defined in TS 24.301)
- 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 PWS (which includes ETWS and CMAS) message transmission
- Optionally performing paging optimisation
- S-GW relocation without UE mobility, as defined in TS 23.401

Functions of S-GW (TS 23.401)

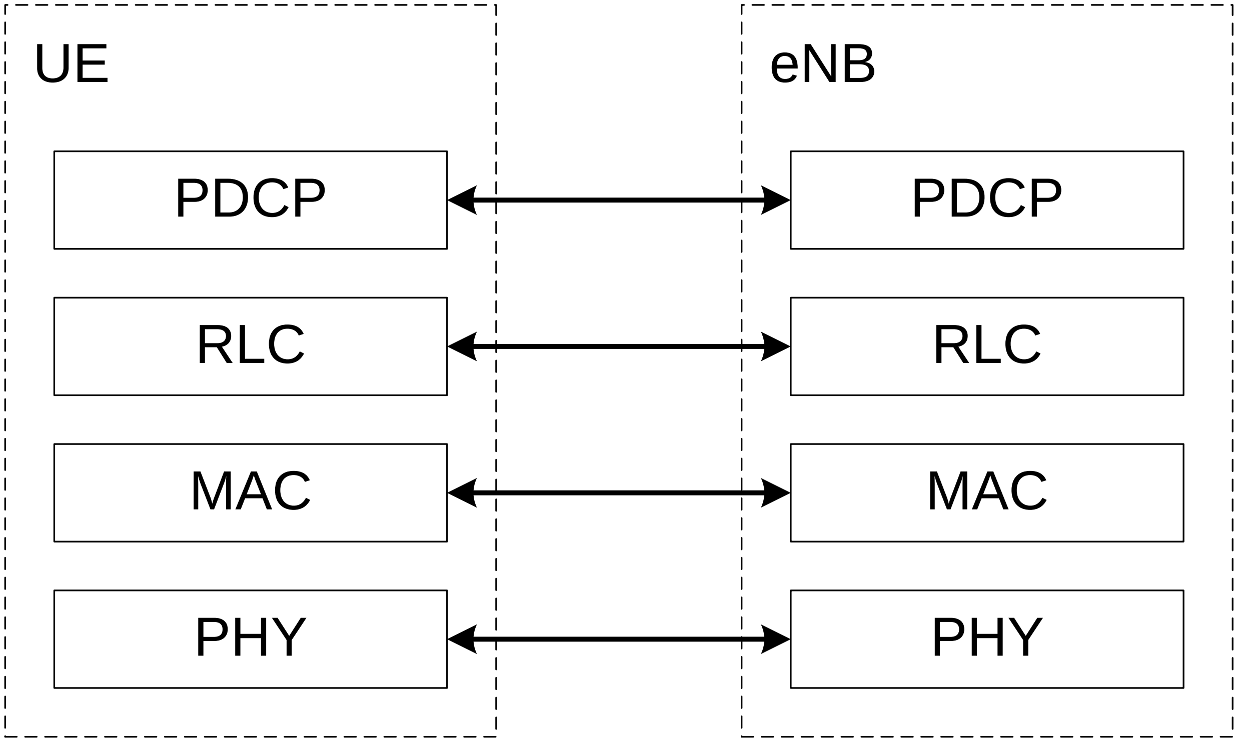
- The local Mobility Anchor point for inter-eNB handover
- Mobility anchoring for inter-3GPP mobility
- E-UTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure
- Lawful Interception
- Packet routing and forwarding
- Transport level packet marking in the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

Functions of P-GW (TS 23.401)

- Per-user based packet filtering (by e.g. deep packet inspection)
- Lawful Interception
- UE IP address allocation
- Transport level packet marking in the uplink and the downlink
- UL and DL service level charging, gating and rate enforcement
- DL rate enforcement based on APN-AMBR

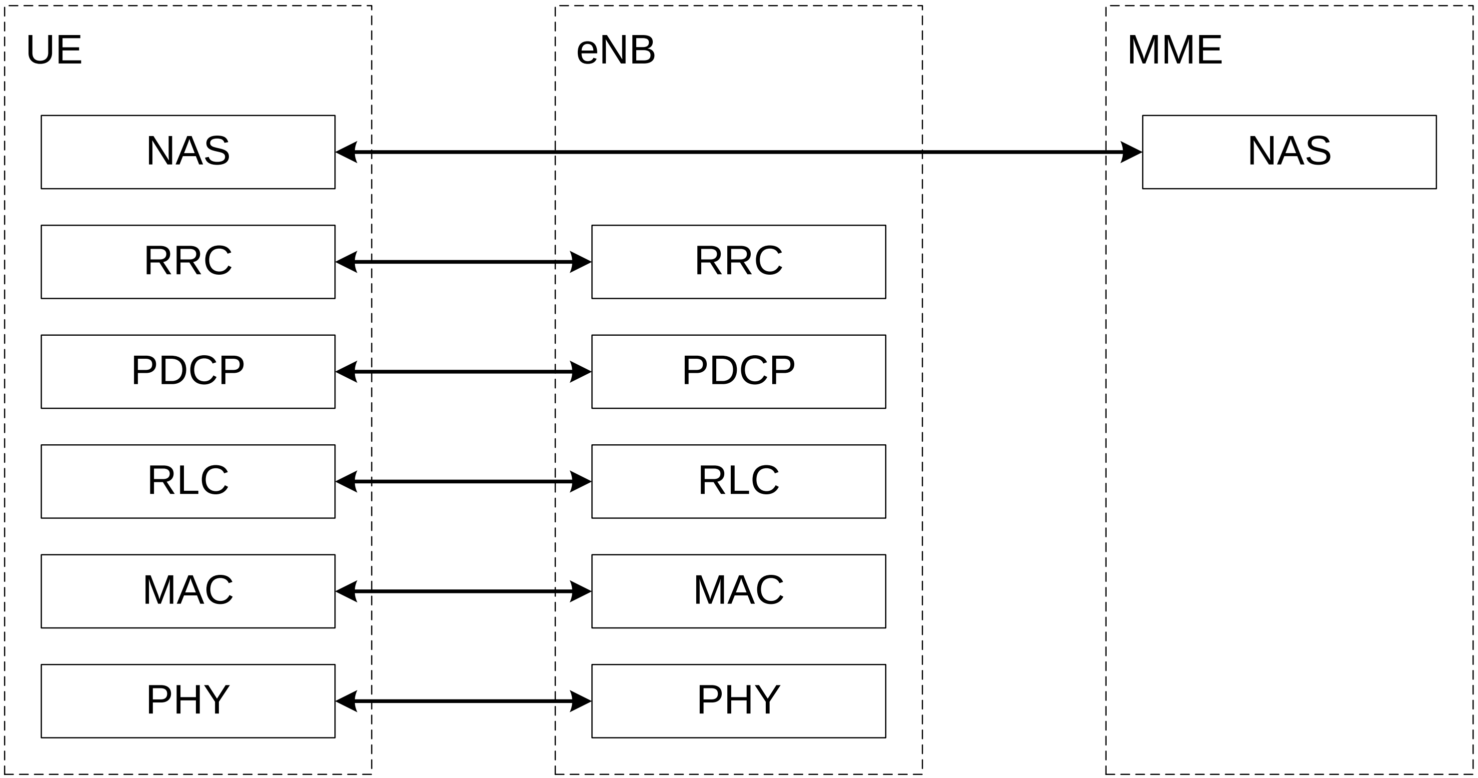
4.3 Radio Protocol Architecture

User-Plane Protocol Stack



For NB-IoT, the user plane is not used when transferring data over NAS

Control-Plane Protocol Stack



- For a NB-IoT UE that only supports Control Plane CIoT EPS, PDCP is bypassed
- For a NB-IoT UE that supports Control Plane CIoT EPS optimization and S1-U data transfer or User Plane CIoT EPS optimization, PDCP is also bypassed until AS security is activated

(see TS 24.301)

Control Plane

- 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, except for NB-IoT
- 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

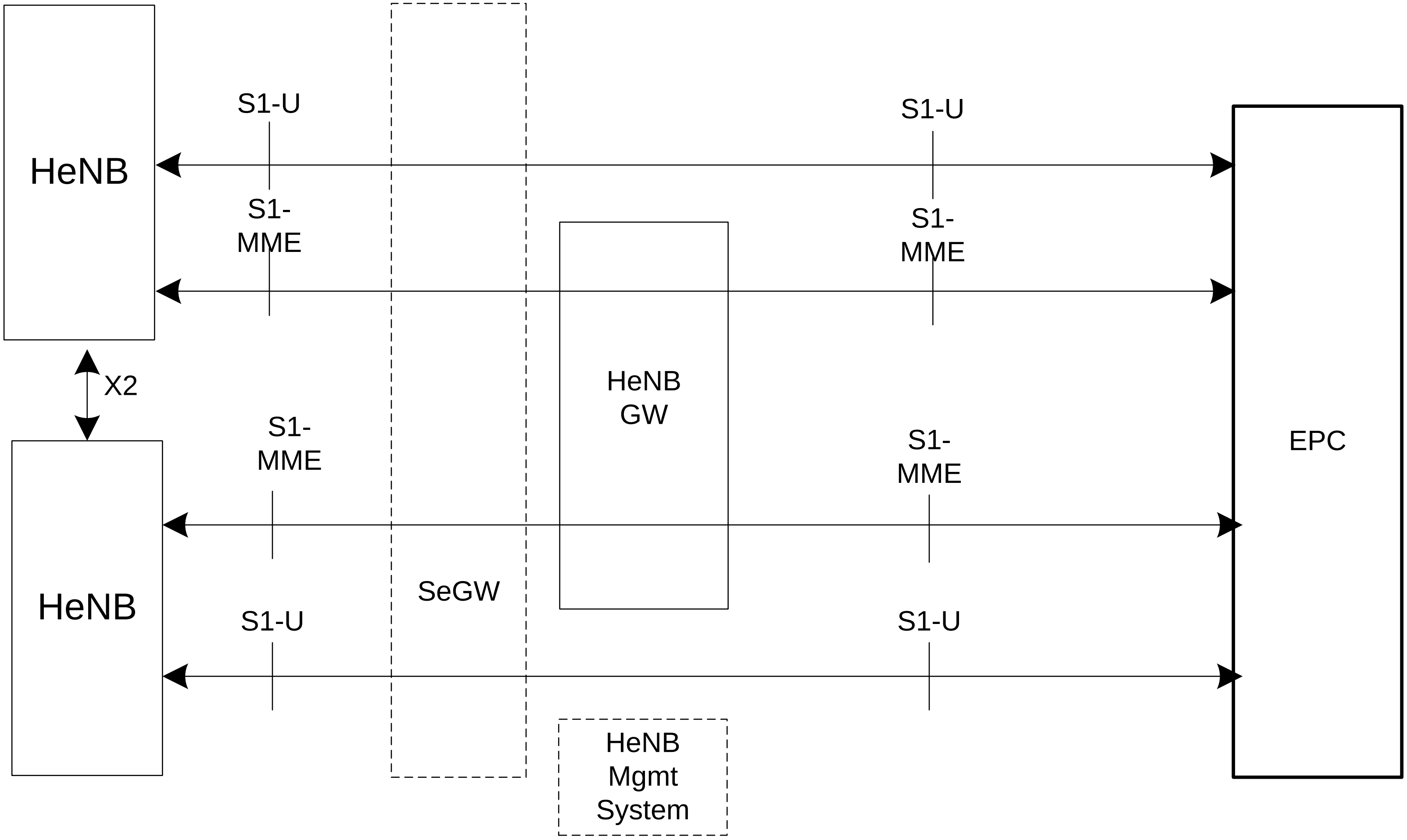
IP Fragmentation

- Fragmentation function in IP layer on S1 and X2 shall be supported
- Configuration of S1-U (X2-U) link MTU in the eNB 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 dependent

4.6 Support of HeNBs (Home eNB)

- The E-UTRAN architecture may deploy a Home eNB Gateway (HeNB GW) to allow the S1 interface between the HeNB and the EPC to support a large number of HeNBs in a scalable manner
- 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

E-UTRAN HeNB Logical Architecture



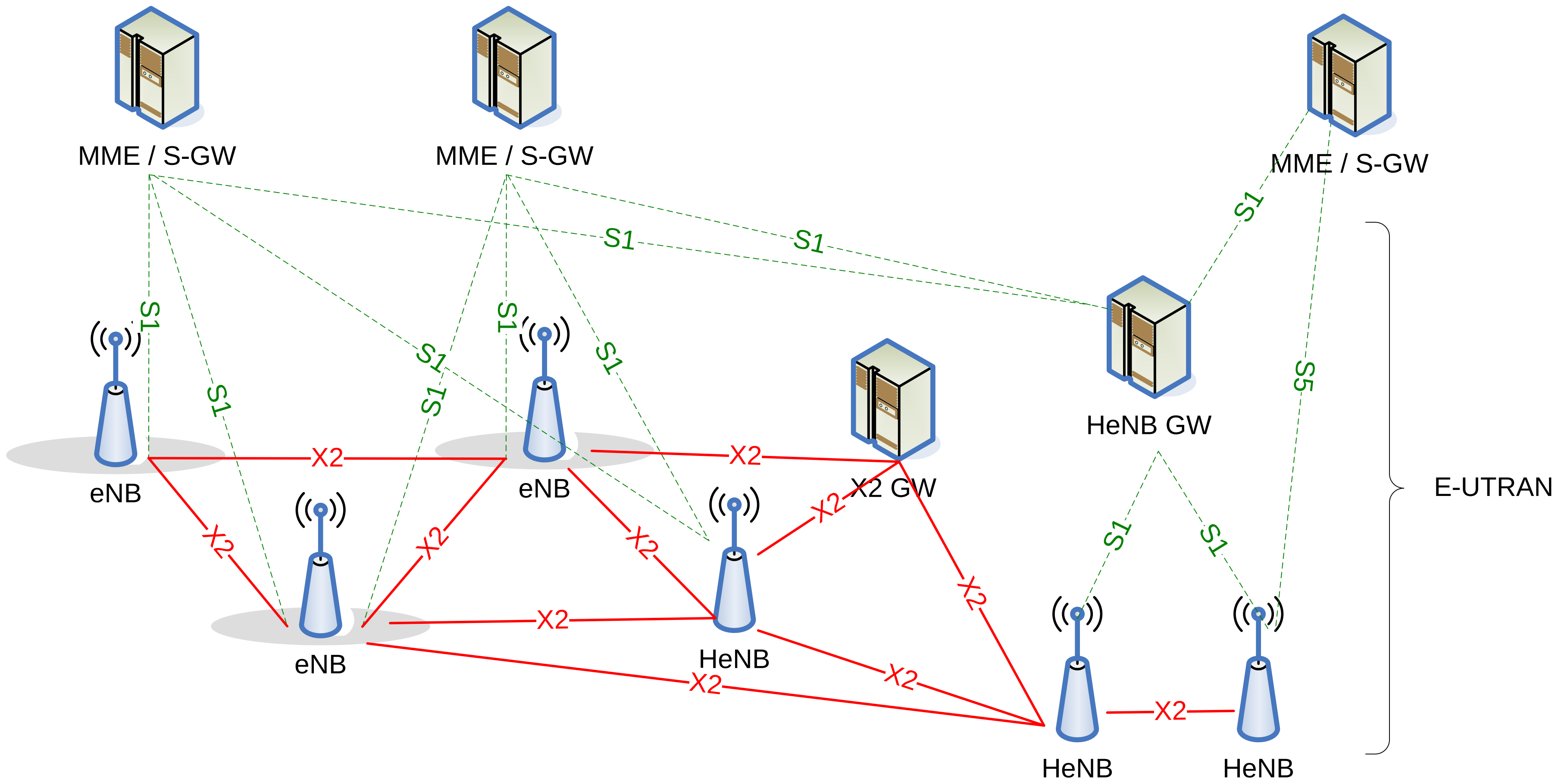
S1 Interface

- 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, regardless 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, and
  - With possible exceptions e.g. NNSF
- the procedures run between a HeNB and the EPC shall be the same as those between an eNB and the EPC
  - With possible exceptions e.g. S5 procedures in case of LIPA support

X2-based HO Support

Source	Target	Notes
eNB or any HeNB	open access HeNB	
eNB, or any HeNB	hybrid access HeNB	
hybrid access HeNB or closed access HeNB	closed access HeNB	Only applies for same CSG ID and PLMN, and if the UE is a member of the CSG cell
Any HeNB	eNB	

Overall E-UTRAN Architecture with Deployed HeNB GW and X2 GW



Functions of HeNB

- 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
  - The HeNB will not simultaneously connect to another HeNB GW, or another MME
- The TAC and PLMN ID used by the HeNB shall also be supported by the HeNB GW
- Selection of an MME at UE attachment is hosted by the HeNB GW instead of the HeNB
  - Upon reception of the GUMMEI from a UE, the HeNB shall include it in the INITIAL UE MESSAGE message
  - Upon reception of the GUMMEI Type from the UE, the HeNB shall also include it in the message if supported and supported by the HeNB GW
- 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
- Signalling the GUMMEI of the Source MME to the HeNB GW in the S1 PATH SWITCH REQUEST message

Regardless of HeNB GW Connection

- The HeNB may support the LIPA function (Section 4.6.5)
- The HeNB may support Fixed Broadband Access network interworking function to signal Tunnel Information to the MME via INITIAL UE MESSAGE message, PATH SWITCH REQUEST message and HANDOVER NOTIFY message as specified in TS 23.139
  - The HeNB may also signal Tunnel Information to the MeNB via SENB ADDITION REQUEST ACKNOWLEDGE message when the HeNB provide SeNB function and the MeNB signal to MME via E-RAB MODIFICATION INDICATION message
  - The Tunnel Information includes the HeNB IP address, the UDP port if NAT/NAPT is detected
- In case an X2 GW is used, the HeNB registers with the X2 GW at power on or after any change of TNL address(es)

Functions of HeNB GW

- Relaying UE-associated S1 application part messages between the MME serving the UE and the HeNB serving the UE
  - Except the UE CONTEXT RELEASE REQUEST message received from the HeNB with an explicit GW Context Release Indication
- Terminating non-UE associated S1 application part procedures towards the HeNB and towards 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
- Routing the S1 PATH SWITCH REQUEST message towards the MME based on the GUMMEI of the source MME received from the HeNB
- Selection of an IP version to be used for S1-U, if a requested ERAB configuration contains two transport layer addresses of different versions

Functions of X2 GW

- Routing the X2AP X2 MESSAGE TRANSFER message to target eNB or HeNB based on the routing information received in the X2AP X2 MESSAGE TRANSFER message
- Informing the relevant (H)eNBs upon detecting that the signalling (i.e. SCTP) connection to a (H)eNB is unavailable. The relevant (H)eNBs are the ones which had an "X2AP association" with this (H)eNB via the X2 GW when the signalling connection became unavailable
- Mapping the TNL address(es) of a (H)eNB to its corresponding Global (H)eNB ID and maintaining the association

Functions of MME (with HeMB GW and X2 GW)

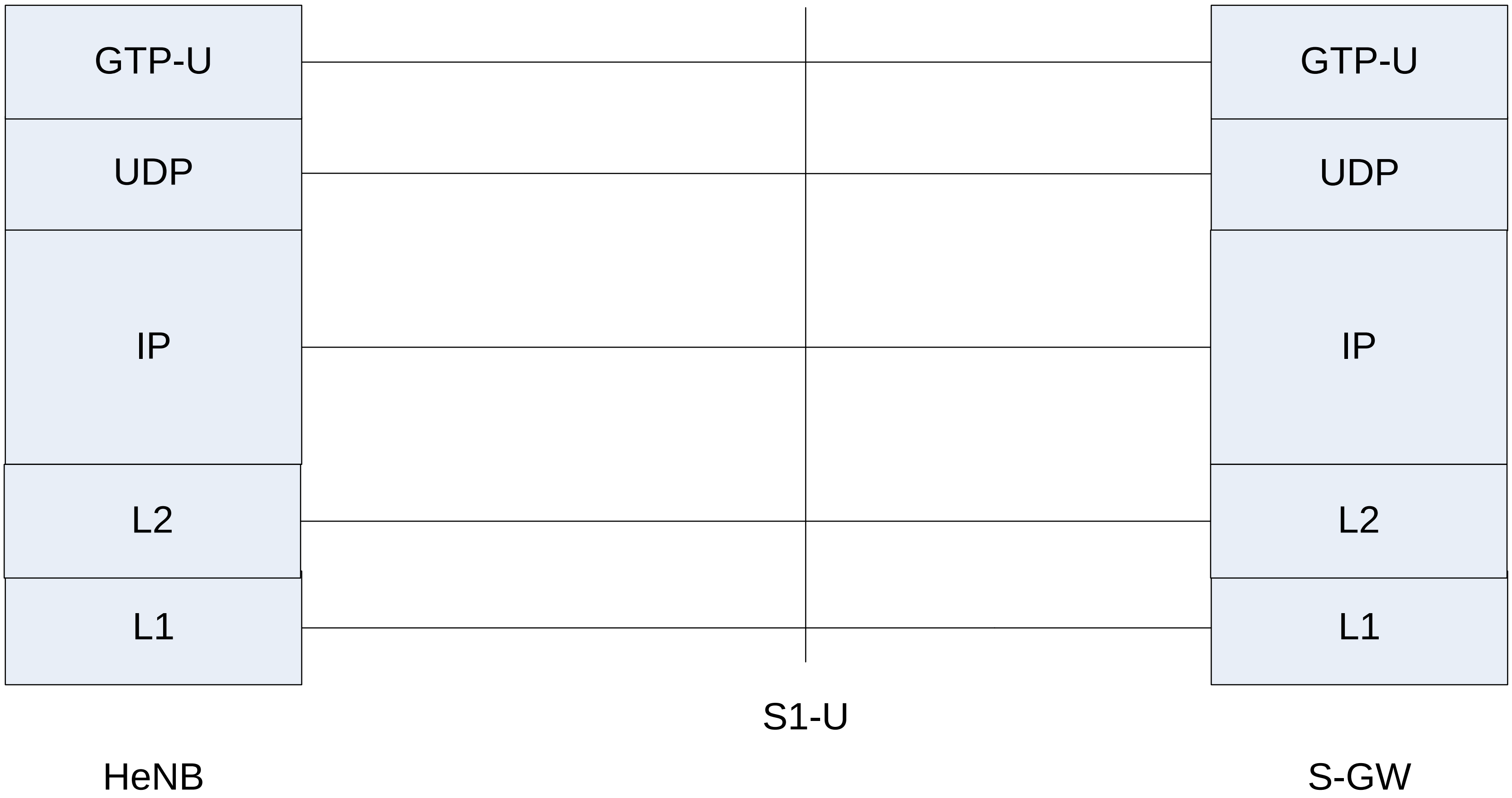
In addition to functions specified in section 4.1

- Access control for UEs that are members of Closed Subscriber Groups (CSG)
  - In case of handovers to CSG cells, access control is based on the target CSG ID of the selected target PLMN provided to the MME by the serving E-UTRAN (TS 23.401)
- Membership Verification for UEs handing over to hybrid cells
  - In case of handovers to hybrid cells the MME performs Membership Verification based on UE's selected target PLMN, cell access mode related information and the CSG ID of the target cell provided by the source E-UTRAN in S1 handover, or provided by the target E-UTRAN in X2 handover (3GPP TS 23.401)
- Membership Verification for UEs for which the hybrid cell is served by an SeNB (Clause 4.9.3.3)
- CSG membership status signalling to the E-UTRAN in case of attachment/handover to hybrid cells and in case of the change of membership status when a UE is served by a CSG cell or a hybrid cell
- Supervising the E-UTRAN action after the change in the membership status of a UE

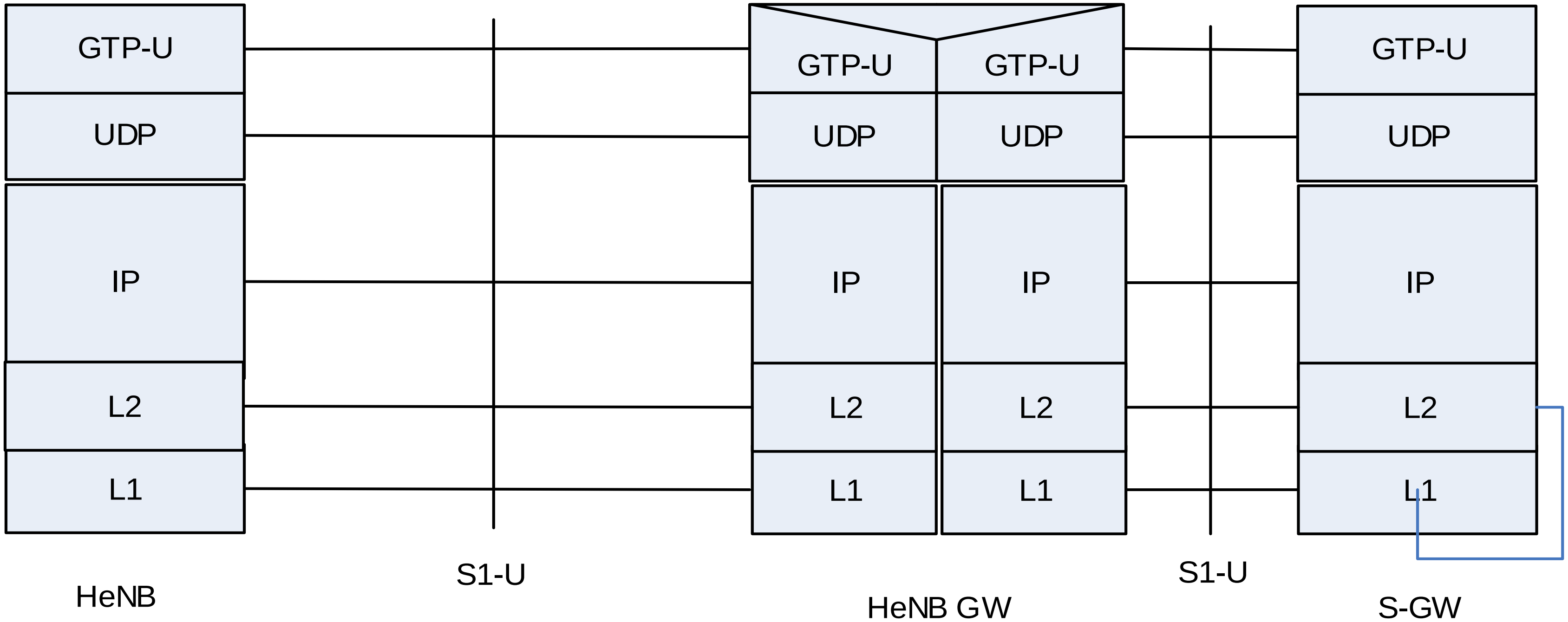
Functions of MME (with HeMB GW and X2 GW) (Cont.)

- In case of a HeNB directly connected
  - Verifying as defined in TS 33.320, that the identity used by the HeNB is valid when receiving the S1 SETUP REQUEST message and determining whether the access mode of the HeNB is closed or not
  - Verifying as defined in TS 33.320, for a closed HeNB, that the indicated cell access mode and CSG ID are valid when receiving the S1 INITIAL UE MESSAGE message, the S1 PATH SWITCH REQUEST and the S1 HANDOVER REQUEST ACKNOWLEDGE message, and
  - Verifying, as defined in TS 33.320, that the indicated HeNB identity is valid when receiving the S1 PWS RESTART INDICATION message and the S1 PWS FAILURE INDICATION message
- Routing of handover messages, MME configuration transfer messages and MME Direct Information Transfer messages towards HeNB GWs based on the TAI contained in these messages
- The MME may support the LIPA function with HeNB
- The MME may support fixed Broadband Access network interworking with HeNB as specified in TS 23.139
- The MME may send two transport layer addresses of different versions only in case of HeNB GW which does not terminate user plane

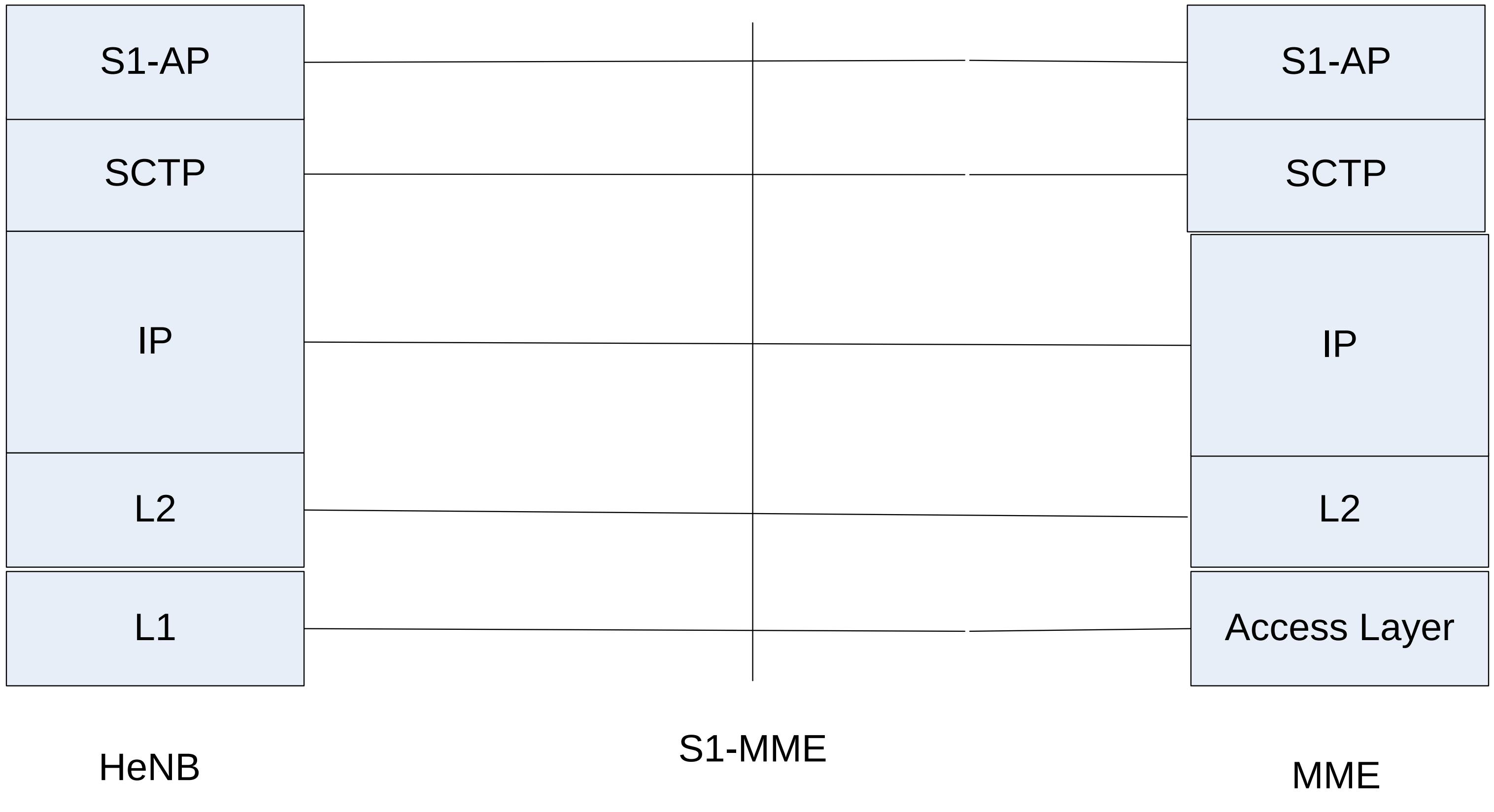
User Plane for S1-U Interface for HeNB without HeNB GW



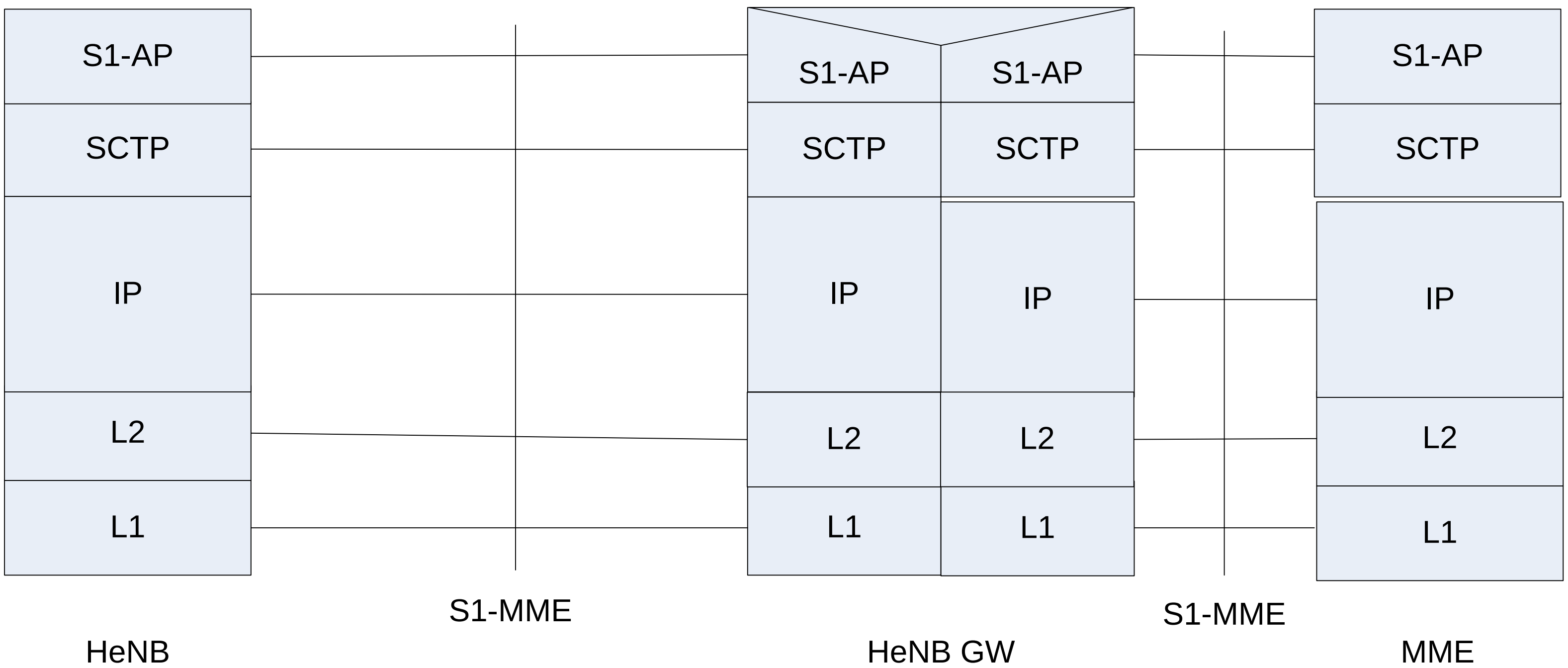
User Plane for S1-U Interface for HeNB with HeNB GW



Control Plane for S1-MME Interface for HeNB to MME without the HeNB GW



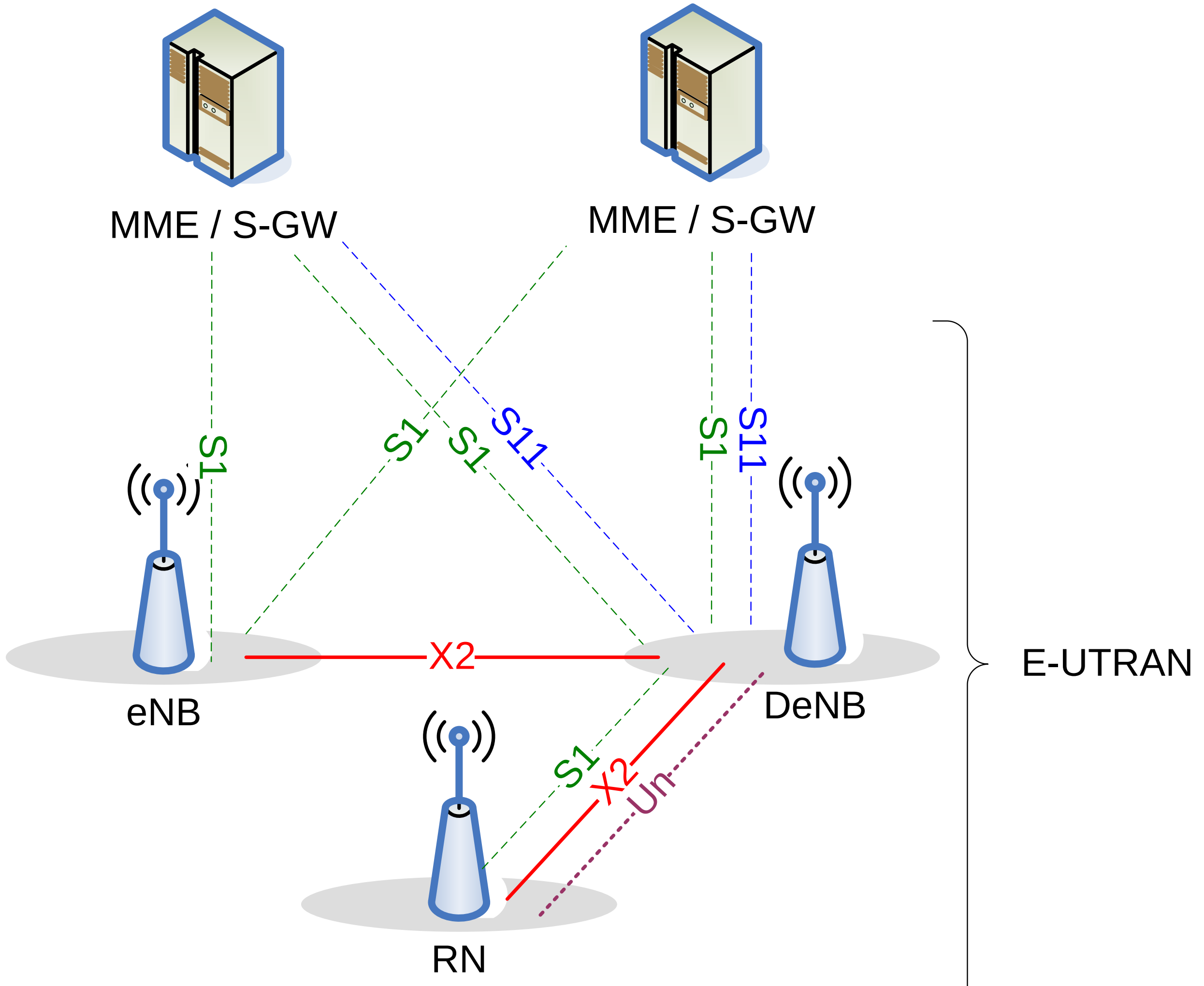
Control Plane for S1-MME Interface for HeNB to MME with the HeNB GW



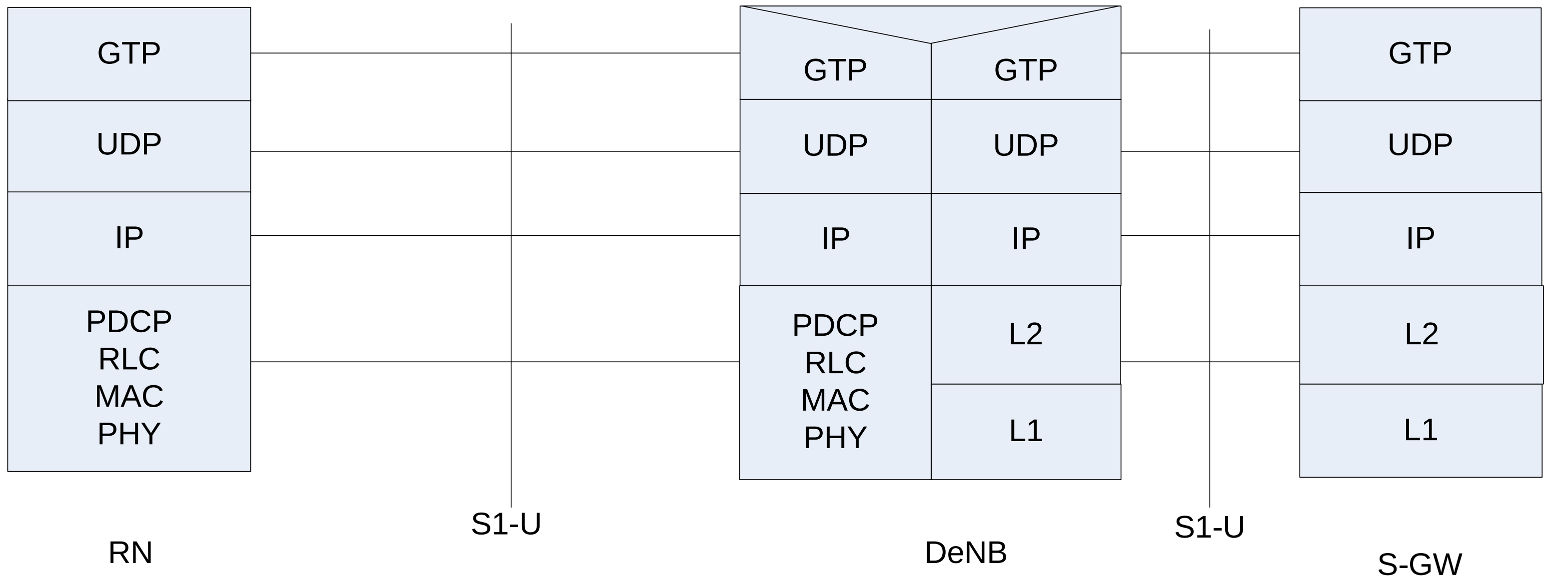
4.7 Support for Relaying

- E-UTRAN supports relaying by having a Relay Node (RN) wirelessly connect to an eNB serving the RN, called Donor eNB (DeNB), via a modified version of the E-UTRA radio interface, the modified version being called the Un interface
- The RN supports the eNB functionality meaning it terminates the radio protocols of the E-UTRA radio interface, and the S1 and X2 interfaces
  - From a specification point of view, functionality defined for eNBs, e.g. RNL and TNL, also applies to RNs unless explicitly specified
  - RNs do not support NNSF
- In addition to the eNB functionality, the RN also supports a subset of the UE functionality, e.g. physical layer, layer-2, RRC, and NAS functionality, in order to wirelessly connect to the DeNB

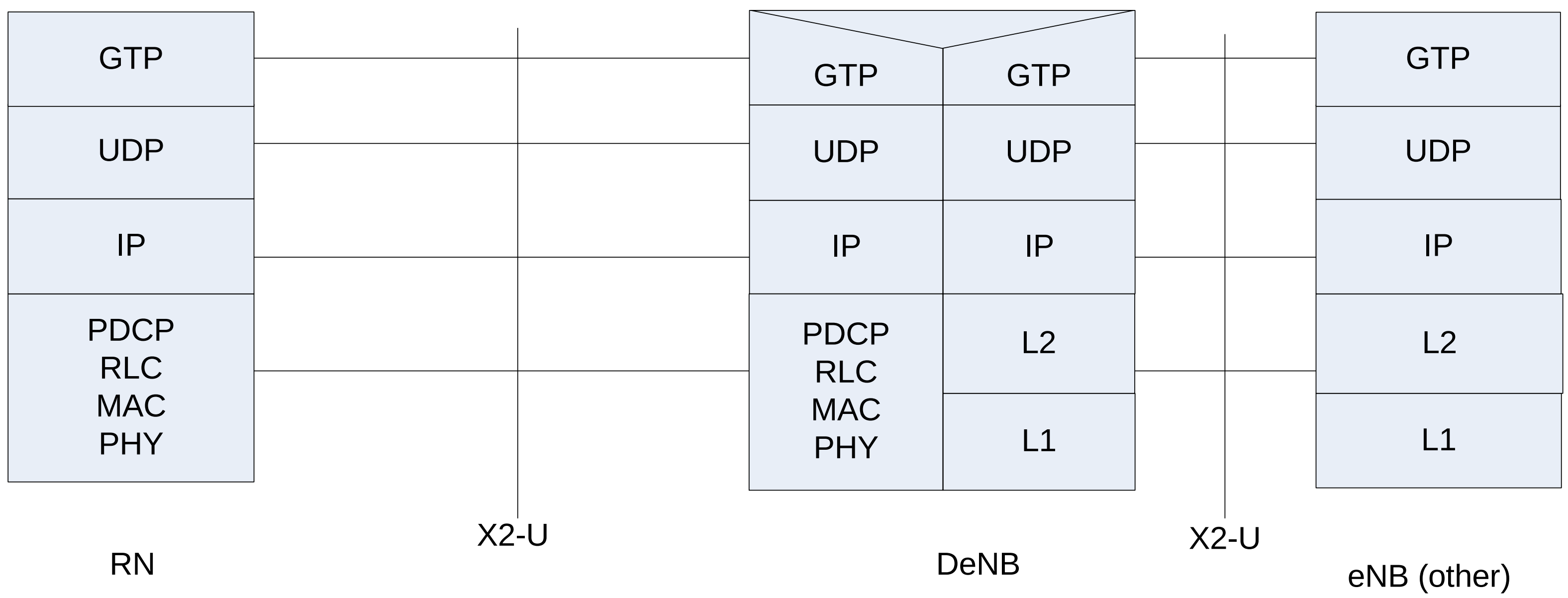
Overall E-UTRAN Architecture Supporting RNs



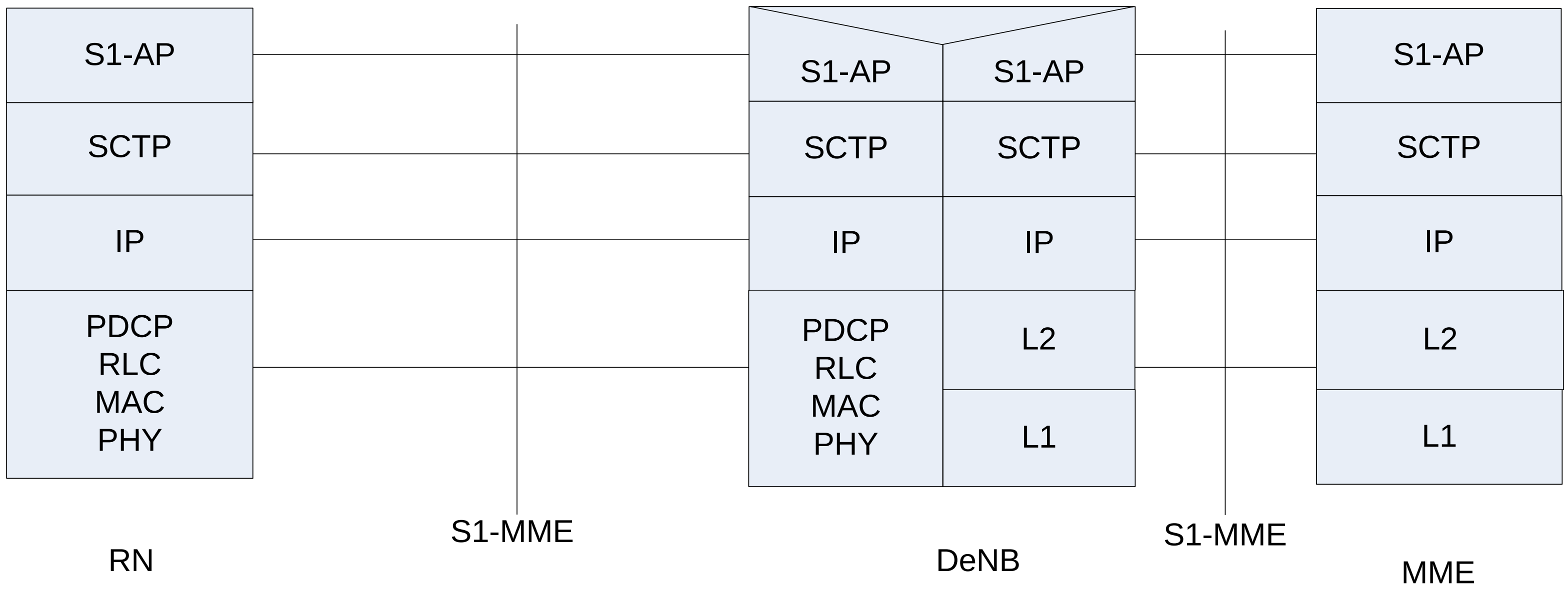
S1 User Plane Protocol Stack for Supporting RNs



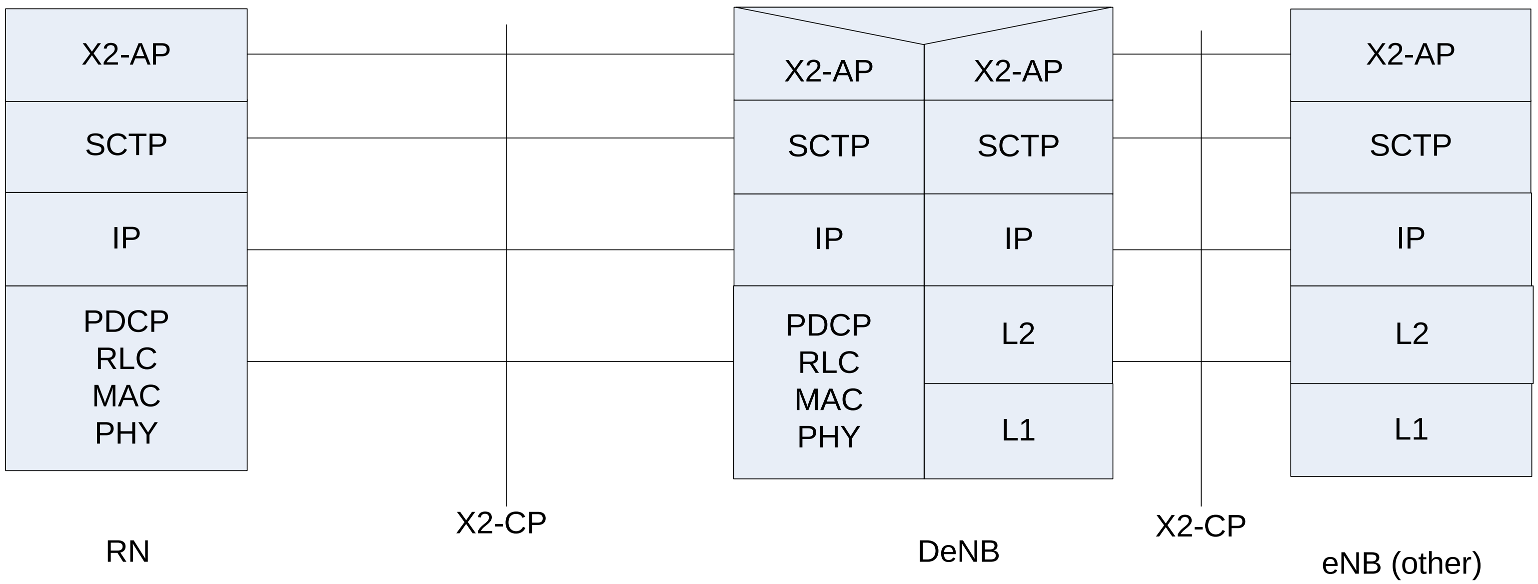
X2 User Plane Protocol Stack for Supporting RNs



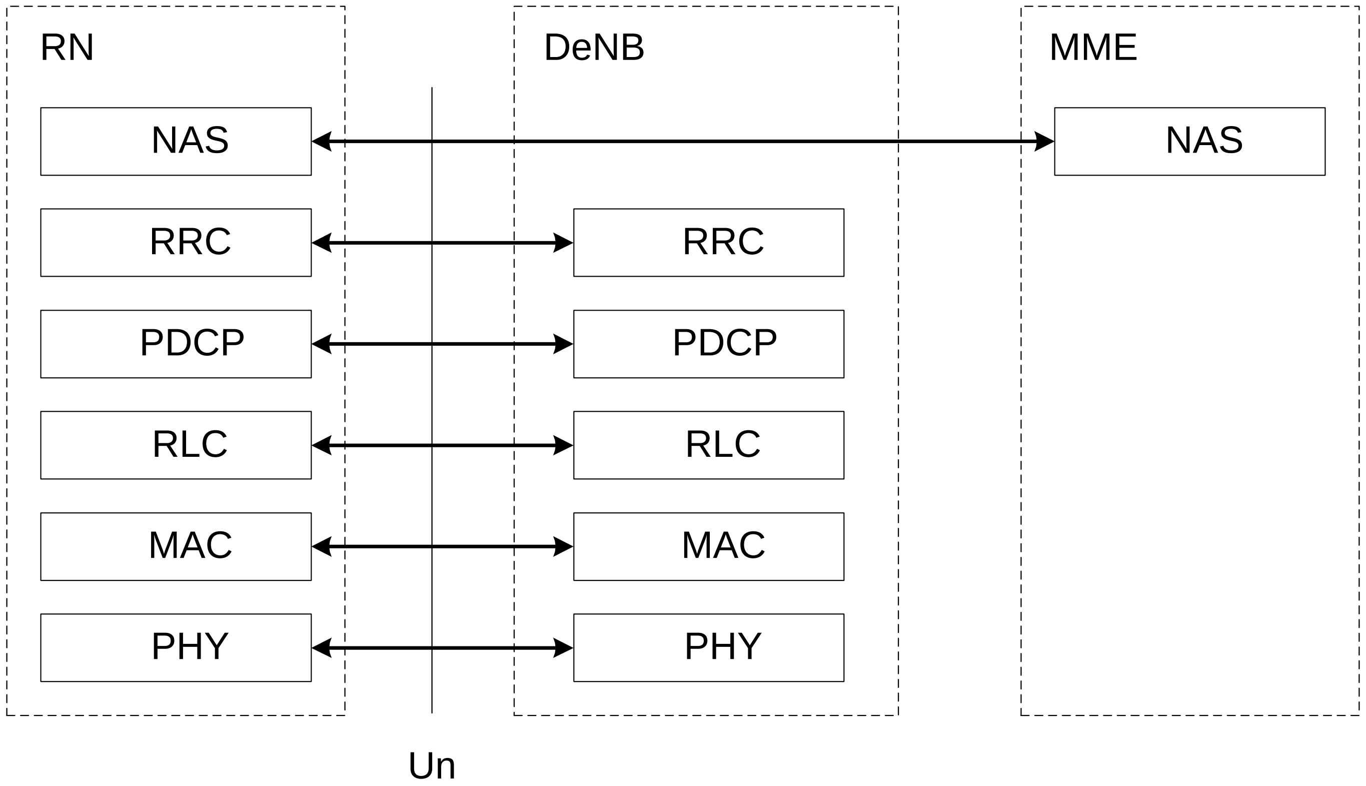
S1 Control Plane Protocol Stack for Supporting RNs



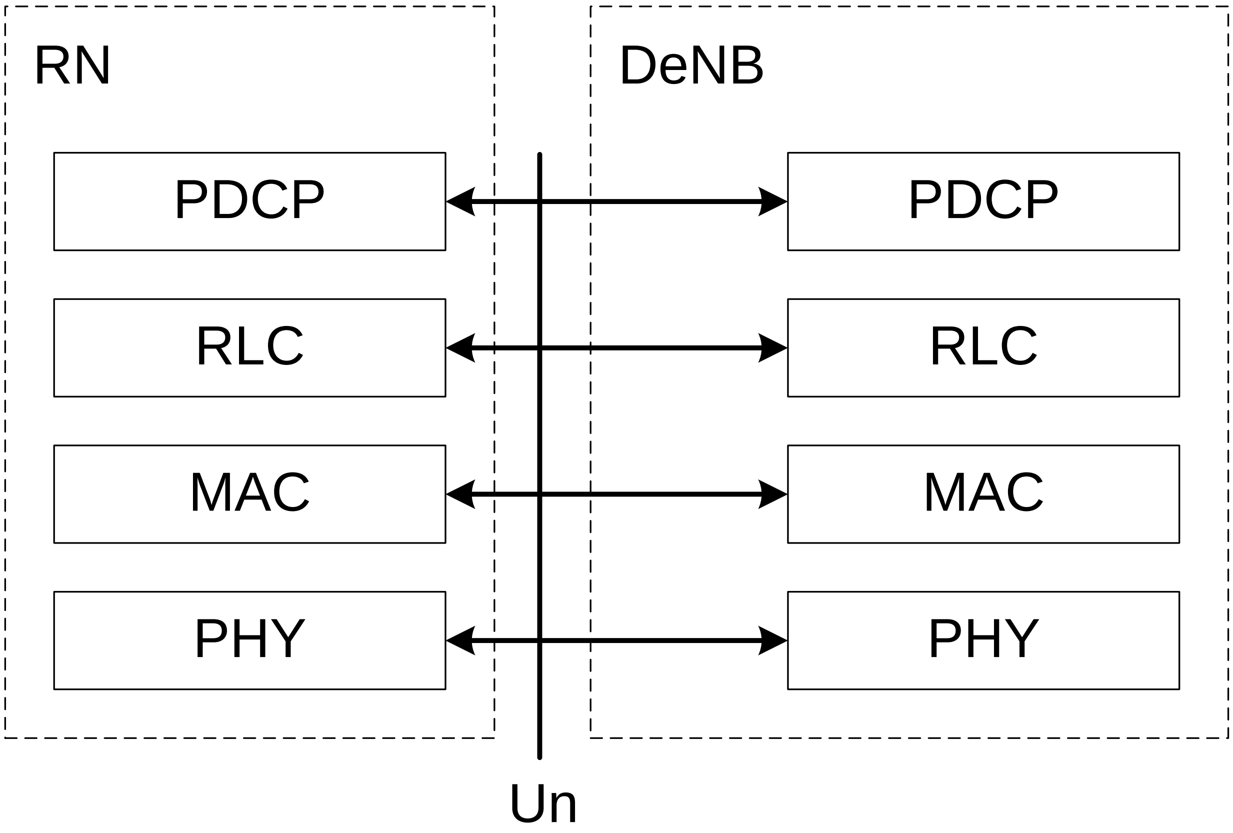
X2 Control Plane Protocol Stack for Supporting RNs



Radio Control Plane Protocol Stack for Supporting RNs



Radio User Plane Protocol Stack for Supporting RNs

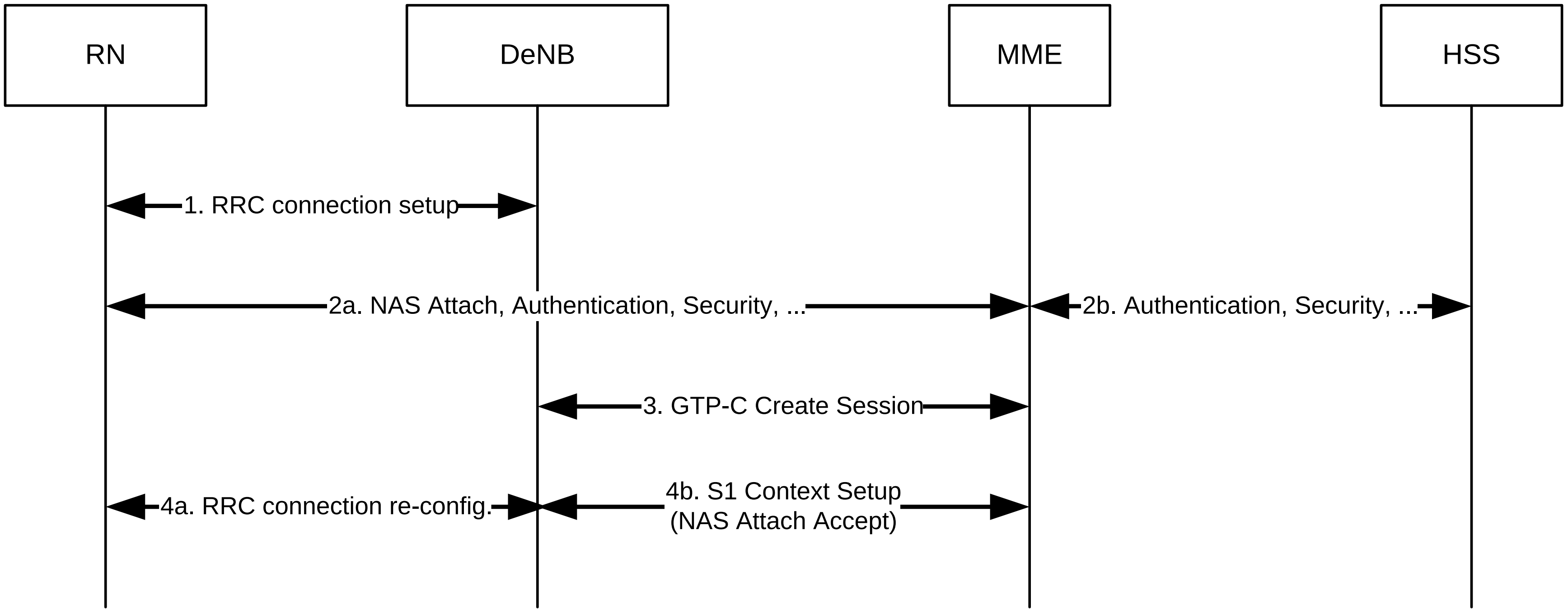


RN Attach Procedure

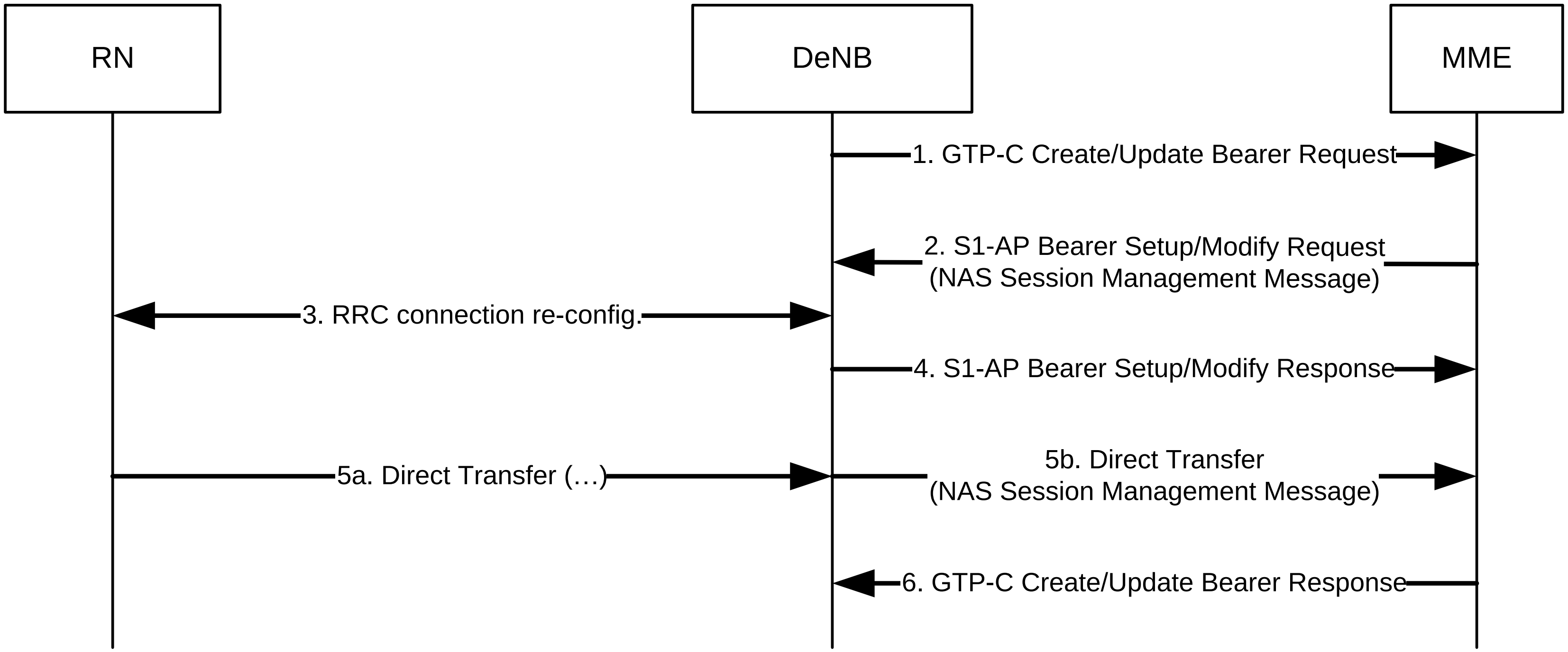
The procedure is the same as the normal UE attach procedure TS 23.401 with the exception that

- The DeNB has been made aware of which MMEs support RN functionality via the S1 Setup Response message earlier received from the MMEs
- The RN sends an RN indication to the DeNB during RRC connection establishment
- After receiving the RN indication from the RN, the DeNB sends the RN indicator and the IP address of the S GW/P-GW function embedded in the DeNB, within the Initial UE Message, to an MME supporting RN functionality
- MME selects S-GW/P-GW for the RN based on the IP address included in the Initial UE Message
- During the attach procedure, the EPC checks if the RN is authorised for relay operation
  - only if the RN is authorised, the EPC accepts the attach and sets up a context with the DeNB
  - otherwise the EPC rejects the attach

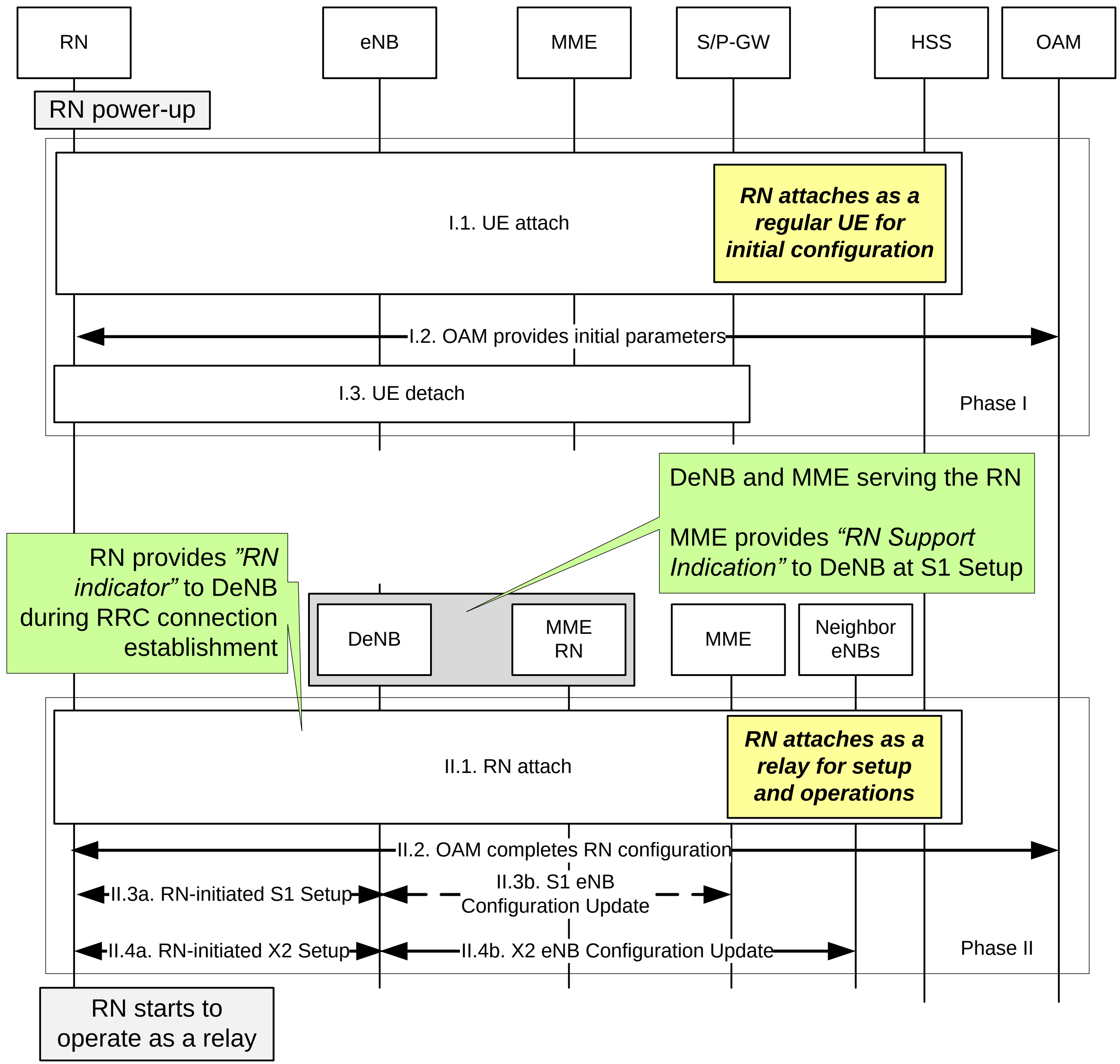
RN Attach Procedure



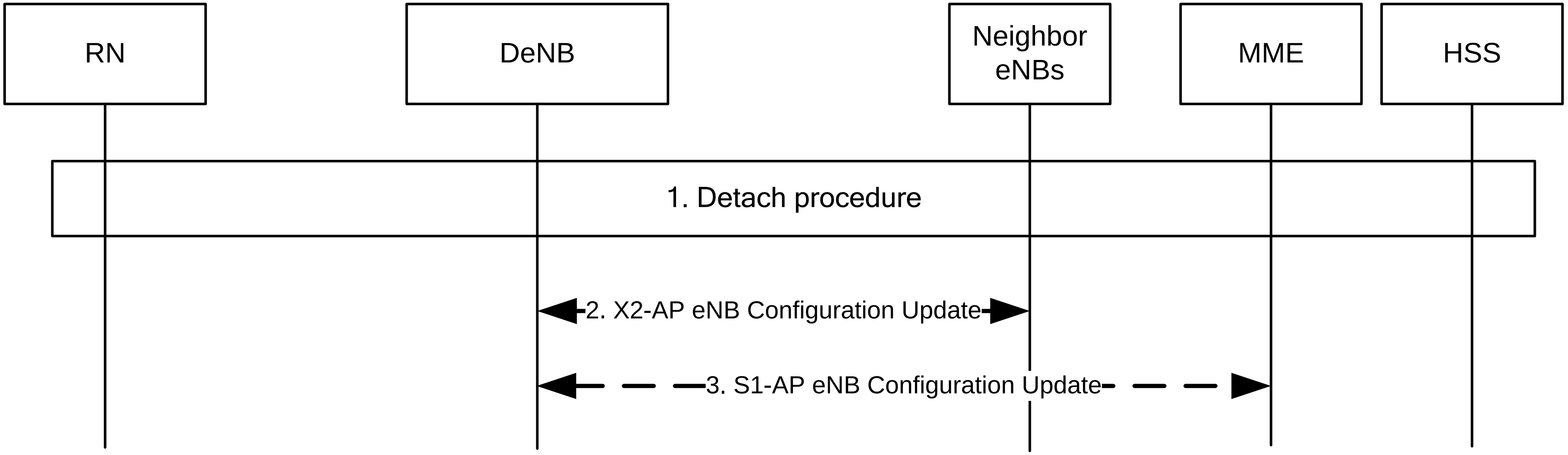
DeNB-initiated Bearer Activation/Modification Procedure



RN Startup Procedure



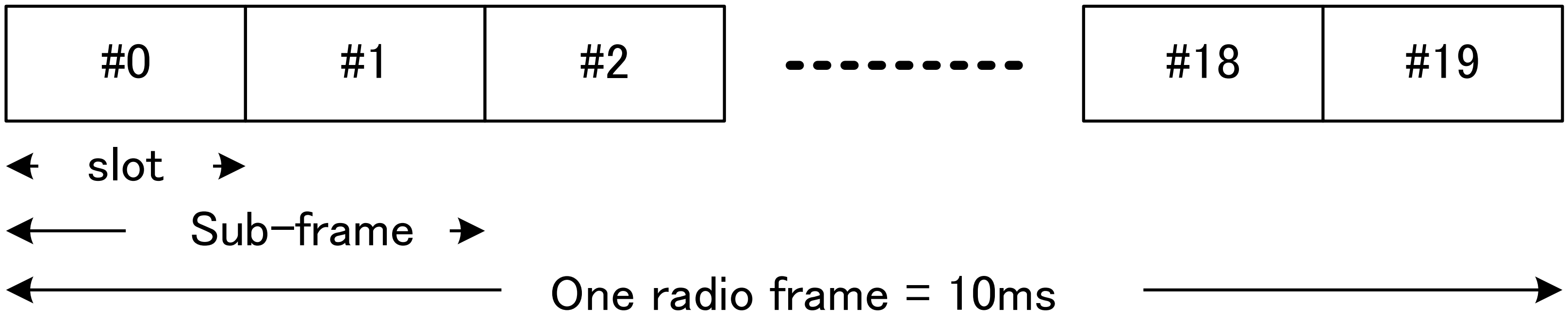
RN Detach Procedure



5. Physical Layer for E-UTRA Frame Structures

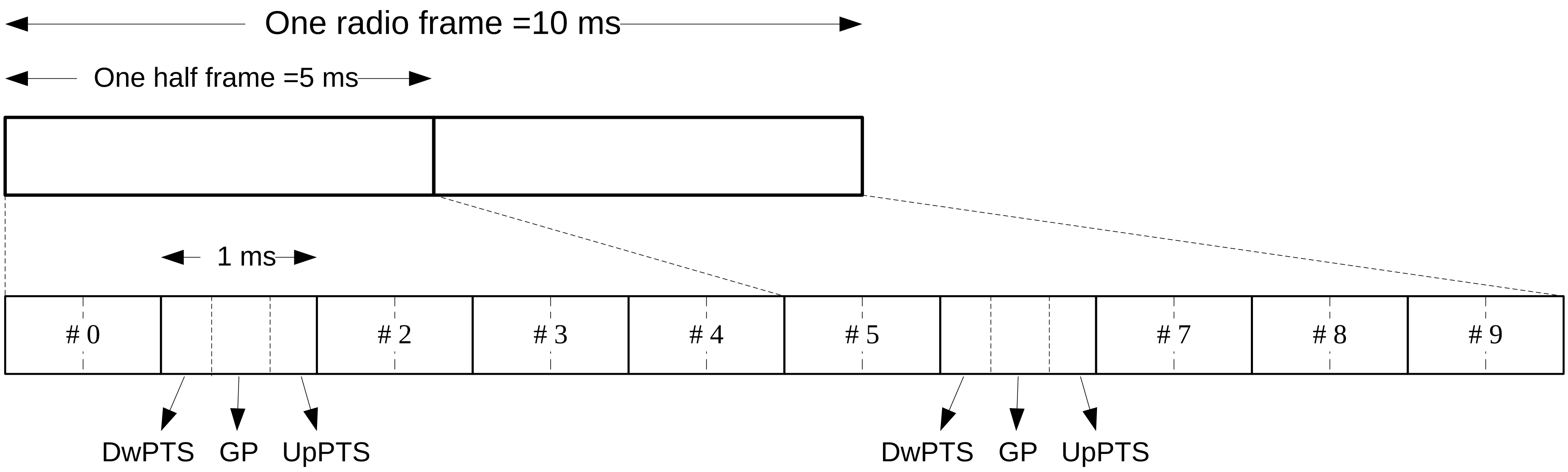
- Downlink and uplink transmissions are organized into radio frames with 10 ms duration
- Three radio frame structures are supported
  - Type 1, applicable to FDD
  - Type 2, applicable to TDD
  - Type 3, applicable to LAA secondary cell operation only

Frame Structure Type 1



- For FDD, 10 subframes, 20 slots, or up to 60 subslots are available for downlink and uplink transmission in each 10 ms interval
  - Each 10 ms radio frame is divided into ten equally sized sub-frames
  - Each sub-frame consists of two equally sized slots
  - Each slot can further be divided into three subslots that may have different sizes
- Uplink and downlink transmissions are separated in the frequency domain

Frame Structure Type 2
(for 5ms Switch-Point Periodicity)



- 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

Frame Structure Type 2
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

- 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
- GP is reserved for downlink to uplink transition, and UpPTS is reserved in NB-IoT
  - Other Subframes/Fields are assigned for either downlink or uplink transmission
  - Uplink and downlink transmissions are separated in the time domain

Frame Structure Type 3

- Applicable to LAA secondary cell operation with normal cyclic prefix only
- Each 10 ms radio frame is divided into ten equally sized sub-frames
- Each sub-frame consists of two equally sized slots
- The 10 subframes within a radio frame are available for downlink or uplink transmissions

Sidelink Transmissions

- Sidelink transmissions are defined for sidelink discovery, sidelink communication and V2X sidelink communication between Ues
- The sidelink transmissions use the same frame structure as the frame structure that is defined for uplink and downlink when UEs are in network coverage
  - However, the sidelink transmission are restricted to a sub-set of the uplink resources in time and frequency domain

Physical Channels of E-UTRA

- 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 and the RN about the number of OFDM symbols used for the PDCCHs
  - Transmitted in every downlink or special subframe
- Physical Hybrid ARQ Indicator Channel (PHICH)
  - Carries Hybrid ARQ ACK/NAKs in response to uplink transmissions
- Physical multicast channel (PMCH)
  - Carries the MCH
- Physical random access channel (PRACH)
  - Carries the random access preamble

Physical Channels of E-UTRA - Downlink

- Physical downlink control channel (PDCCH)
  - Informs the UE and the RN about the resource allocation of PCH and DL-SCH, and Hybrid ARQ information related to DL-SCH
  - Carries the uplink scheduling grant
  - Carries the sidelink scheduling grant
- Enhanced physical downlink control channel (EPDCCH)
  - Informs the UE about the resource allocation of DL-SCH, and Hybrid ARQ information related to DL-SCH;
  - Carries the uplink scheduling grant
  - Carries the sidelink scheduling grant
- MTC physical downlink control channel (MPDCCH)
  - Informs the UE about the resource allocation of DL-SCH, and Hybrid ARQ information related to DL-SCH
  - Carries Hybrid ARQ ACK in response to uplink transmissions
  - Carries the uplink scheduling grant
  - Carries the direct indication information
- Short physical downlink control channel (SPDCCH)
  - Informs the UE about the resource allocation of DL-SCH, and Hybrid ARQ information related to DL-SCH
  - Carries the uplink scheduling grant
- Physical downlink shared channel (PDSCH)
  - Carries the DL-SCH and PCH

Physical Channels of E-UTRA - Uplink

- Physical uplink control channel (PUCCH)
  - Carries Hybrid ARQ ACK/NAKs in response to downlink transmission;
  - Carries Scheduling Request (SR)
  - Carries CSI reports
- Short physical uplink control channel (SPUCCH)
  - Carries Hybrid ARQ ACK/NAKs in response to downlink transmission;
  - Carries Scheduling Request (SR)
- Physical uplink shared channel (PUSCH)
  - Carries the UL-SCH
- Relay physical downlink control channel (R-PDCCH)
  - Informs the RN about the resource allocation of DL-SCH, and Hybrid ARQ information related to DL-SCH
  - Carries the uplink scheduling grant

Physical Channels of E-UTRA - Sidelink

- Physical sidelink broadcast channel (PSBCH)
  - Carries system and synchronization related information, transmitted from the UE
- Physical sidelink discovery channel (PSDCH)
  - Carries sidelink discovery message from the UE
- Physical sidelink control channel (PSCCH)
  - Carries control from a UE for sidelink communication and V2X sidelink communication
- Physical sidelink shared channel (PSSCH)
  - Carries data from a UE for sidelink communication and V2X sidelink communication

Physical Channels of E-UTRA - Narrowband

- Narrowband Physical broadcast channel (NPBCH)
  - The coded BCH transport block is mapped to sixty four subframes within a 640 ms interval
  - 640 ms timing is blindly detected, i.e. there is no explicit signalling indicating 640 ms timing
- Narrowband Physical downlink shared channel (NPDSCH)
  - Carries the DL-SCH and PCH for NB-IoT UEs
- Narrowband Physical downlink control channel (NPDCCH)
  - Informs the NB-IoT UE about the resource allocation of PCH and DL-SCH
  - Carries the uplink scheduling grant for the NB-IoT UE
  - Carries the direct indication information
- Narrowband Physical uplink shared channel (NPUSCH)
  - Carries the UL-SCH and Hybrid ARQ ACK/NAKs in response to downlink transmission for the NB-IoT UE
  - Carries SR for the NB-IoT UE
- Narrowband Physical random access channel (NPRACH)
  - Carries the random access preamble for the NB-IoT UE
  - Carries SR for the NB-IoT UE

DL Physical Layer Procedure

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
2. Power control
   - Downlink power control can be used
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
     - If a resynchronization signal is transmitted in the downlink, it can be used to re-acquire time and frequency synchronization with the cell
   - The primary and secondary synchronization signals are transmitted over the centre 72 sub-carriers in the first and sixth subframe of each frame
     - The resynchronization signals are transmitted over 2 consecutive PRBs. The time and frequency positions of the resynchronization signal (if transmitted) are configurable
   - Neighbour-cell search is based on the same downlink signals as initial cell search

DL 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)

DL PHY Measurements within E-UTRAN

- For measurements within E-UTRAN, two basic UE measurement quantities **shall be** supported
  - Reference signal received power (RSRP): based on the following signals
    - Cell-specific reference signals; or
    - CSI reference signals in configured discovery signals; or
    - Narrowband secondary synchronization signal for NB-IoT UE
  - Reference signal received quality (RSRQ)
- The following UE measurement quantity **may be** supported
  - Received signal strength indicator (RSSI)
  - Reference signal singal to noise and interference ratio (RS-SINR)

Physical Uplink Control Channel

- PUCCH/SPUCCH shall be mapped to a control channel resource in uplink
- PUCCH/SPUCCH is transmitted on PCell, PUCCH SCell (if such is configured in CA) and on PSCell (in DC)
  - The physical layer supports simultaneous transmission of PUCCH and subframe PUSCH, or of SPUCCH and (sub)slot-PUSCH
  - In case of SPUCCH and (sub)slot-PUSCH transmission, both the shared channel and the associated control channel shall be of the same transmission duration (slot or subslot)
- Depending on presence or absence of uplink timing synchronization, the uplink physical control signalling for scheduling request can differ

Physical Uplink Control Channel - Signalling

- In the case of time synchronization being present for the pTAG, the outband control signalling consists of
  - CSI: informs the scheduler about the current channel conditions as seen by the UE
    - If MIMO transmission is used, the CSI includes necessary MIMO-related feedback
  - ACK/NAK
    - The HARQ feedback in response to downlink data transmission consists of a single ACK/NAK bit per transport block in case of non-bundling configuration
  - Scheduling Request (SR)
    - PUCCH/SPUCCH resources for SR, CSI reporting and possibly HARQ feedback are assigned and can be revoked through RRC signaling
    - 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/SPUCCH resources for SR, CSI and HARQ feedback are lost when the UE is no longer synchronized

Uplink Reference Signal

- For PUSCH demodulation, uplink demodulation reference signals are transmitted in the 4-th block of the slot in normal CP
- In case of subslot-PUSCH, the presence and position of demodulation reference signals are indicated to the UE
- Uplink demodulation reference signals are also transmitted for PUCCH demodulation
- The uplink demodulation reference signals sequence length equals the size (number of sub-carriers) of the assigned resource

- The uplink reference signals are based on sequences having constant amplitude and zero autocorrelation

Created Uplink Reference Signals

Multiple reference signals can be created:

- For full-PRB transmission
  - Based on different base sequences;
  - Different shifts of the same sequence;
  - Different orthogonal sequences (OCC) on DM RS.
- For sub-PRB transmission of PUSCH
  - Based on different base sequences;
  - Different cyclic shifts of the same sequence;
  - A common Gold sequence

In addition to demodulation reference signals, the physical layer supports sounding reference signals (SRS)

UL Physical Channel Procedure

1. Link adaptation
   – To guarantee the required minimum transmission performance of each UE while maximizing the system throughput
     • such as the user data rate, packet error rate, and latency
   – Three types of link adaptation are performed according to the channel conditions, the UE capability
     • Adaptive transmission bandwidth
     • Transmission power control
     • Adaptive modulation and channel coding rate
2. Uplink power control
   – Intra-cell power control: the power spectral density of the uplink transmissions can be influenced by the eNB
     • For DC, two types of power control modes are defined, mode 1 and mode 2 as specified in TS 36.213
       – A UE capable of DC supports at least power control mode 1 and the UE may additionally support power control mode 2
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

Transport Channels

- Transport Channel: the physical layer transport services are described by ***how*** and with what characteristics data are transferred over the radio interface
  - The physical layer offers information transfer services to MAC and higher layers
- Downlink transport channel types
  - Broadcast Channel (BCH)
  - Downlink Shared Channel (DL-SCH)
  - Paging Channel (PCH)
  - Multicast Channel (MCH)
- Uplink transport channel types
  - Uplink Shared Channel (UL-SCH)
  - Random Access Channel(s) (RACH)
- Sidelink transport channel types
  - Sidelink broadcast channel (SL-BCH)
  - Sidelink discovery channel (SL-DCH)
  - Sidelink shared channel (SL-SCH)

Downlink Transport Channel Types

- Broadcast Channel (BCH)
  - fixed, pre-defined transport format
  - requirement to be broadcast in the entire coverage area of the cell
- Downlink Shared Channel (DL-SCH)
  - support for HARQ
  - support for dynamic link adaptation by varying 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
- Paging Channel (PCH)
  - 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
- Multicast Channel (MCH)
  - 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

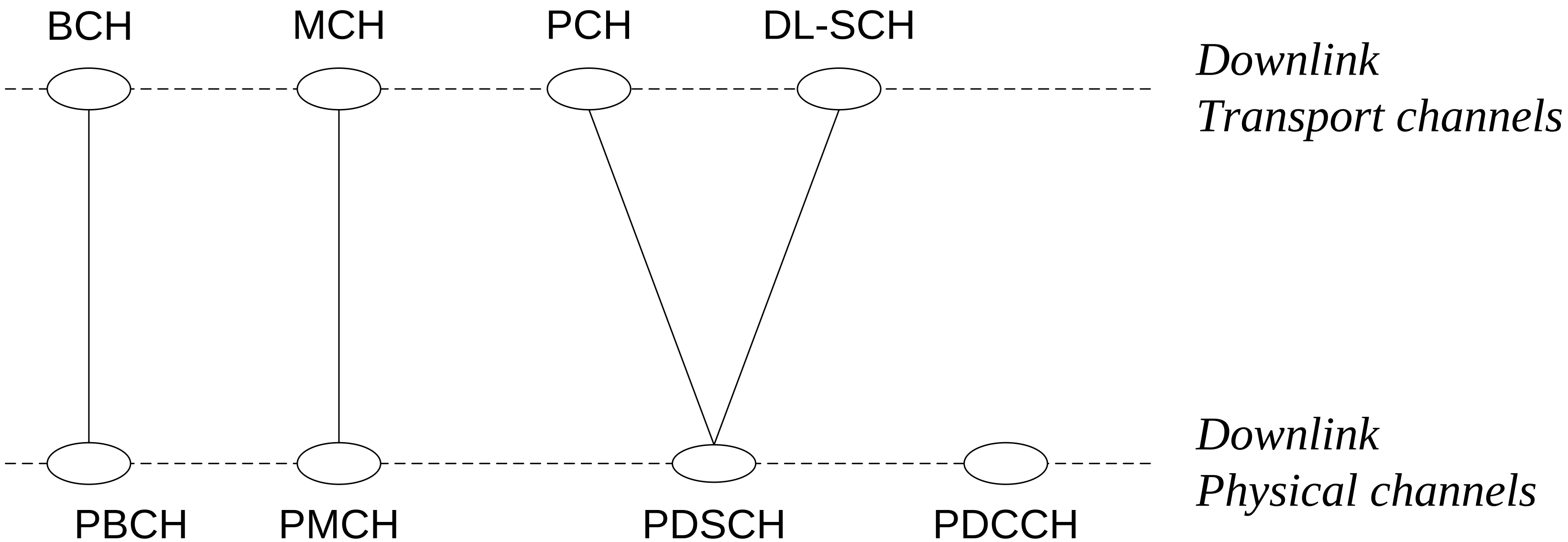
Uplink Transport Channel Types

- Uplink Shared Channel (UL-SCH)
  - 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
- Random Access Channel(s) (RACH)
  - limited control information
  - collision risk

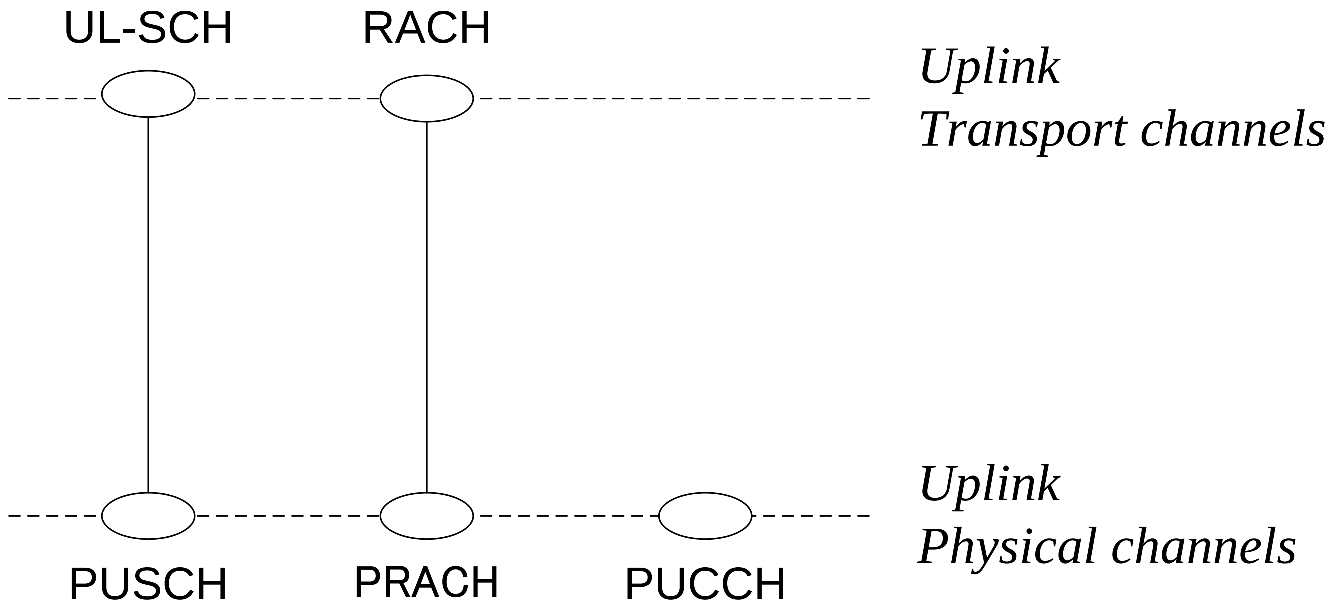
Sidelink Transport Channel Types

- Sidelink broadcast channel (SL-BCH)
  - pre-defined transport format
- Sidelink discovery channel (SL-DCH)
  - fixed size, pre-defined format periodic broadcast transmission
  - support for both UE autonomous resource selection and scheduled resource allocation by eNB
  - collision risk due to support of UE autonomous resource selection; no collision when UE is allocated dedicated resources by the eNB
  - support for HARQ combining, but no support for HARQ feedback
- Sidelink shared channel (SL-SCH)
  - support for broadcast transmission
  - support for both UE autonomous resource selection and scheduled resource allocation by eNB
  - collision risk due to support of UE autonomous resource selection; no collision when UE is allocated dedicated resources by the eNB
  - support for HARQ combining, but no support for HARQ feedback
  - support for dynamic link adaptation by varying the transmit power, modulation and coding

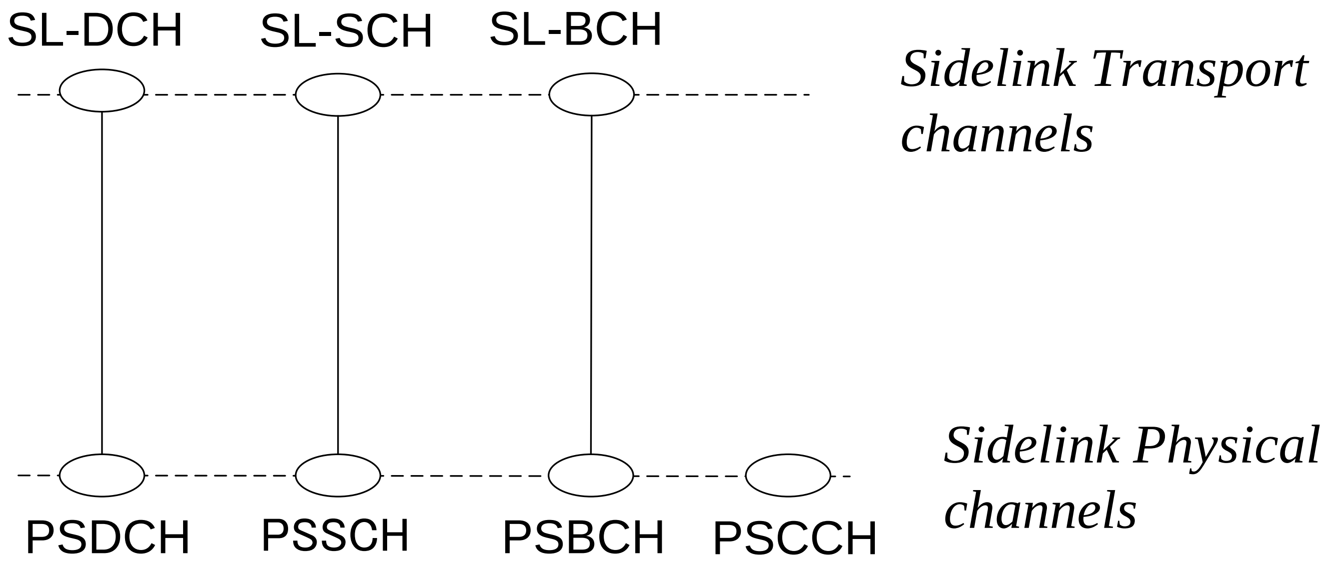
Mapping between Downlink Transport Channels and Downlink Physical Channels



Mapping between Uplink Transport Channels and Uplink Physical Channels



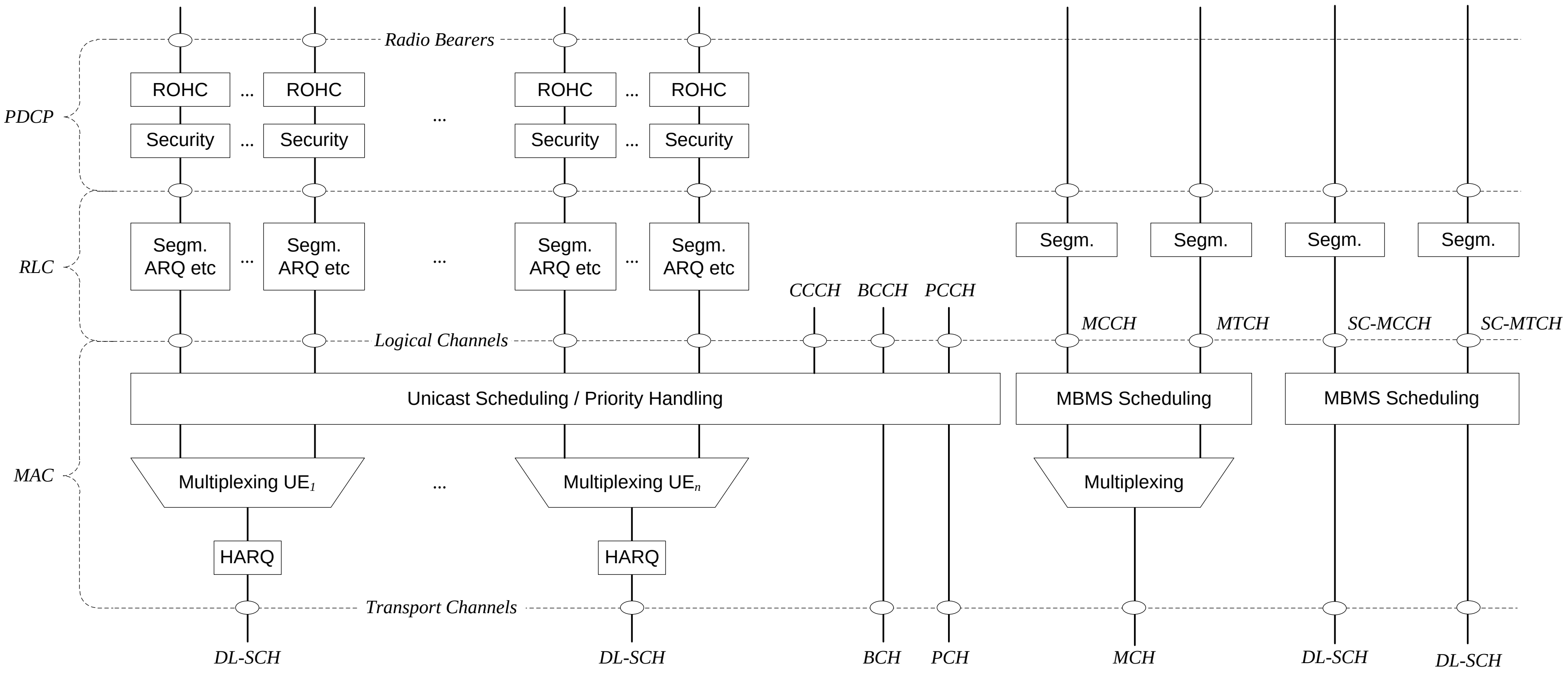
Mapping between Sidelink Transport Channels and Sidelink Physical Channels



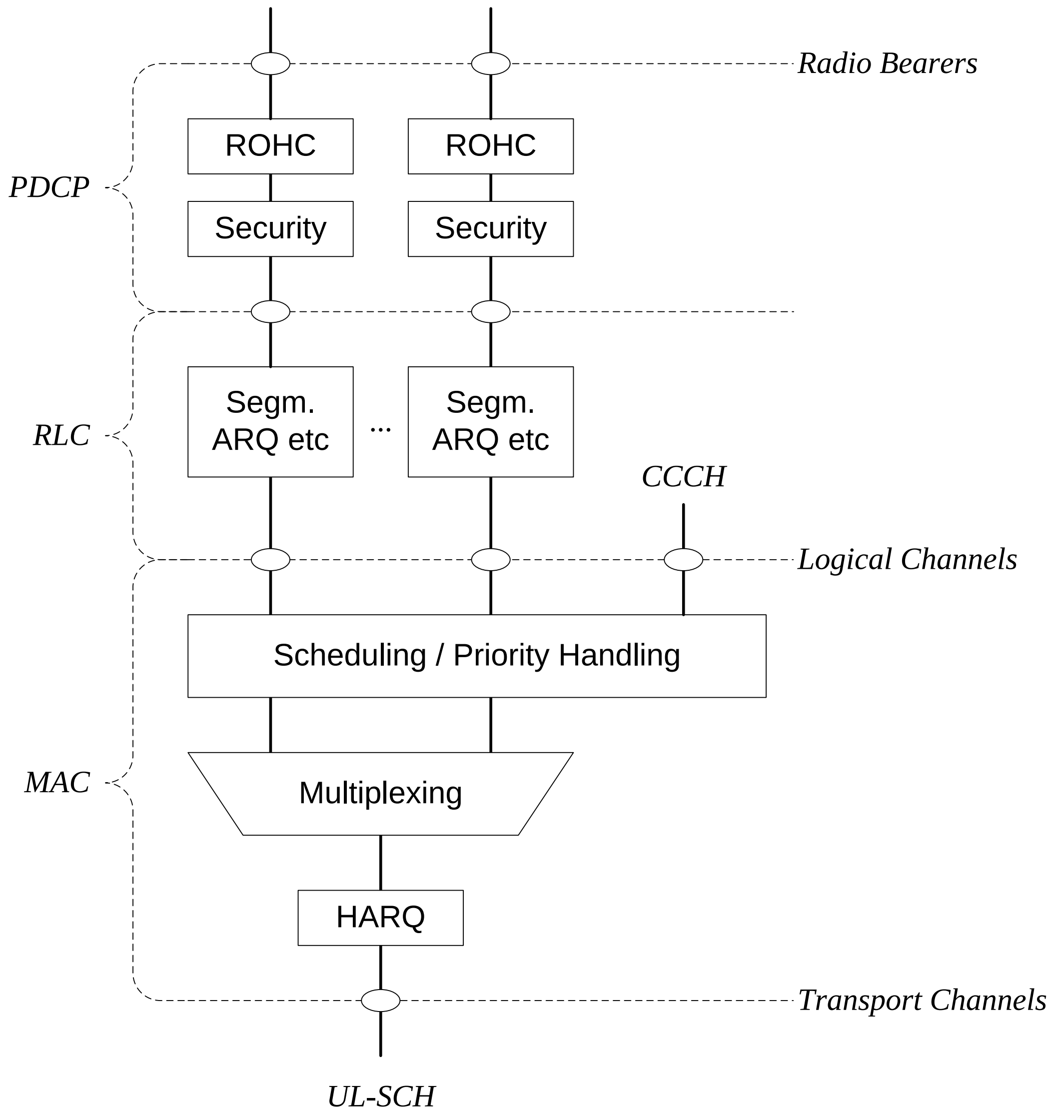
6. Layer 2

- 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 three figures below depict the PDCP/RLC/MAC architecture for downlink, uplink and Sidelink, 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, when neither CA nor DC are configured, only one transport block is generated per TTI in the absence of spatial multiplexing
  - In Sidelink, only one transport block is generated per TTI

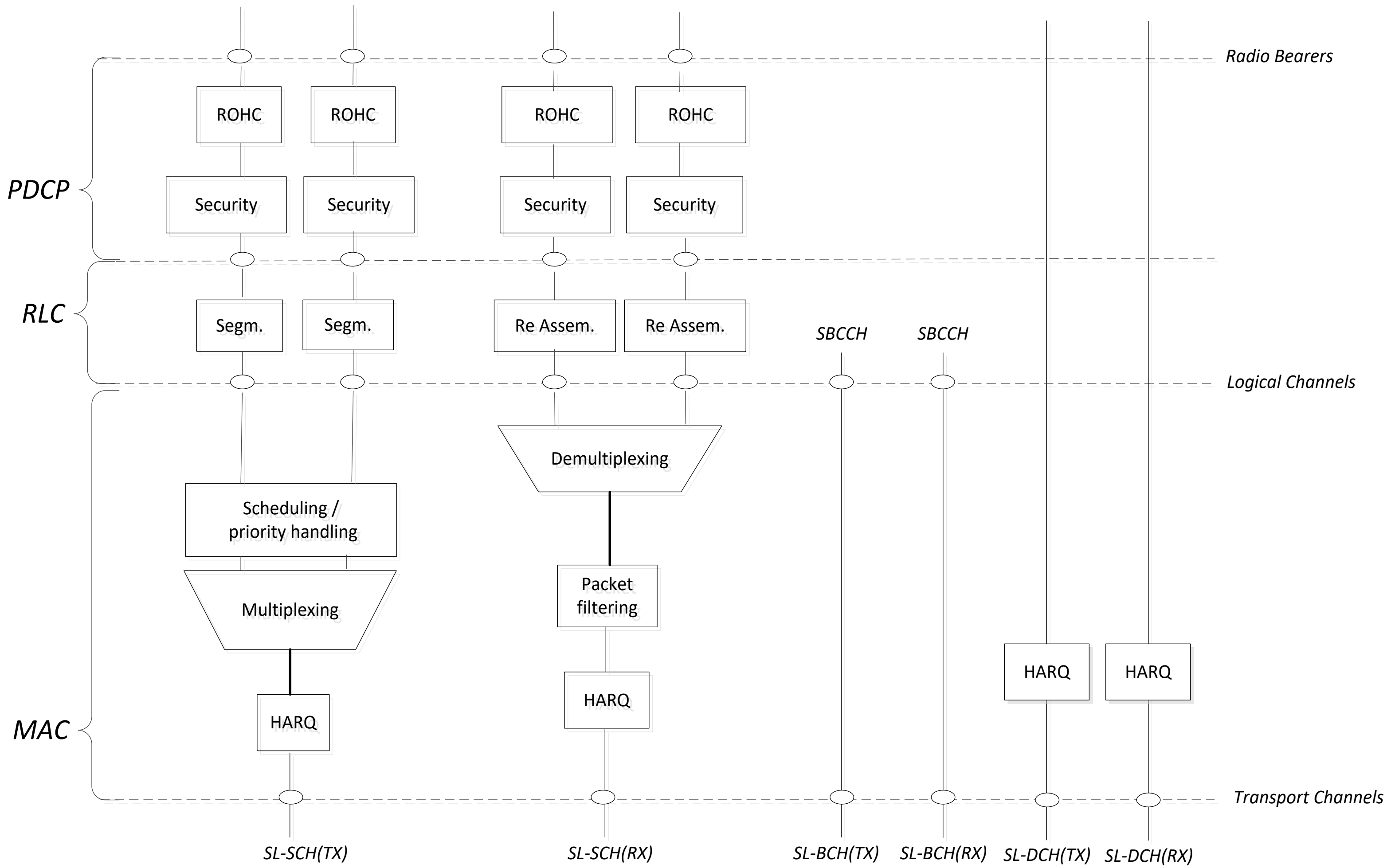
Layer 2 Structure for DL



Layer 2 Structure for UL



Layer 2 Structure for Sidelink



MAC Sublayer - 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
- MBMS service identification
- Transport format selection
- Padding

MAC 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 CG
  - MAC generally consists of several function blocks (transmission scheduling functions, per UE functions, MBMS functions, MAC control functions, transport block generation…)
  - Transparent Mode is only applied to BCCH, BR-BCCH, PCCH and SBCCH

MAC Logical Channels - 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
- Bandwidth Reduced Broadcast Control Channel (BR-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

MAC Logical Channels - Control Channels (Cont.)

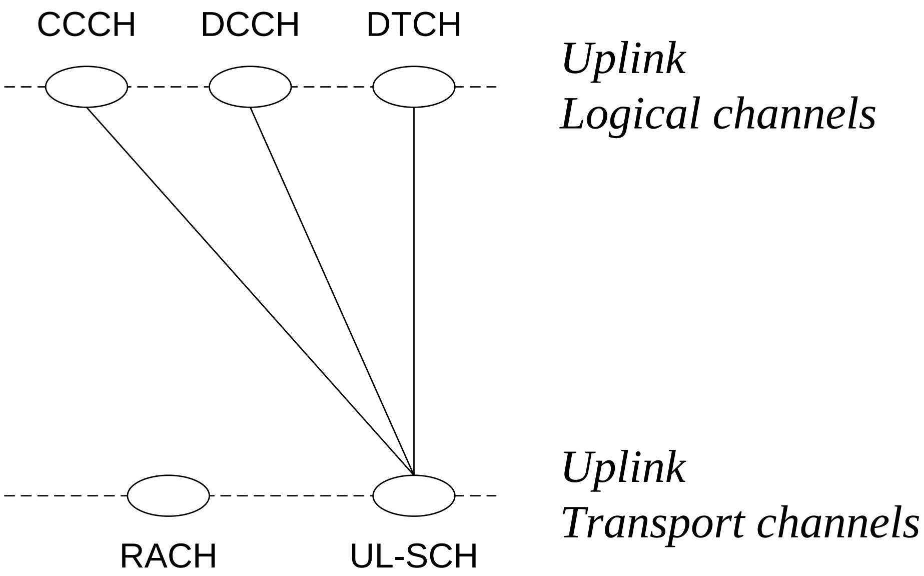
- Multicast Control Channel (MCCH)
  - A point-to-multipoint downlink channel used for transmitting MBMS control information from the network to the UE, for one or several MTCHs
  - This channel is only used by UEs that receive or are interested to receive MBMS
- Single-Cell Multicast Control Channel (SC-MCCH)
  - A point-to-multipoint downlink channel used for transmismitting MBMS control information from the network to the UE, for one or several SC-MTCHs
  - This channel is only used by UEs that receive or are interested to receive MBMS using SC-PTM
- 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
- Sidelink Broadcast Control Channel (SBCCH)
  - A sidelink channel for broadcasting sidelink system information from one UE to other UE(s)

MAC Logical Channels - Traffic Channels

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

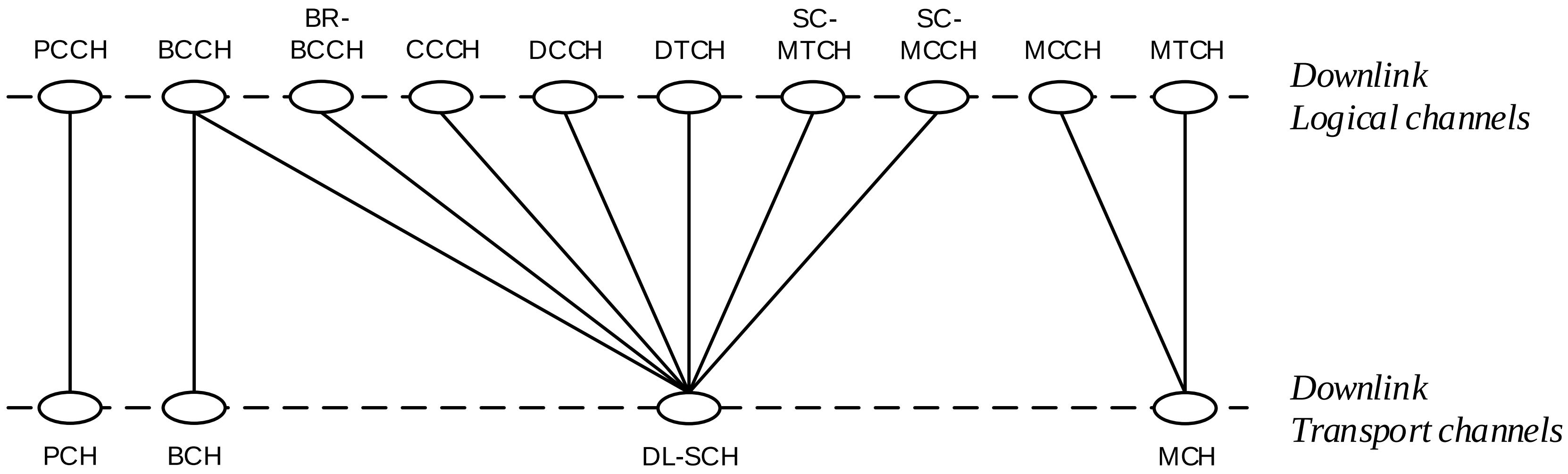
- Dedicated Traffic Channel (DTCH)
  - A point-to-point channel, dedicated to one UE, for the transfer of user information
  - A DTCH can exist in both uplink and downlink
  - DTCH is not supported for a NB-IoT UE that only uses Control Plane CIoT EPS optimizations, as defined in TS 24.301
- Multicast Traffic Channel (MTCH)
  - A point-to-multipoint downlink channel for transmitting traffic data from the network to the UE
  - This channel is only used by UEs that receive MBMS
- Single-Cell Multicast Traffic Channel (SC-MTCH)
  - A point-to-multipoint downlink channel for transmitting traffic data from the network to the UE using SC-PTM transmission
  - This channel is only used by UEs that receive MBMS using SC-PTM
- Sidelink Traffic Channel (STCH)
  - A Sidelink Traffic Channel (STCH) is a point-to-multipoint channel, for transfer of user information from one UE to other UE(s)
  - This channel is used only by sidelink communication capable UEs and V2X sidelink communication capable Ues
  - Point-to-point communication between two sidelink communication capable UEs is also realized with an STCH

Mapping between Uplink Logical Channels and Uplink Transport Channels



- The following connections exist
  - CCCH can be mapped to UL-SCH
  - DCCH can be mapped to UL- SCH
  - DTCH can be mapped to UL-SCH

Mapping between Downlink Logical Channels and Downlink Transport Channels



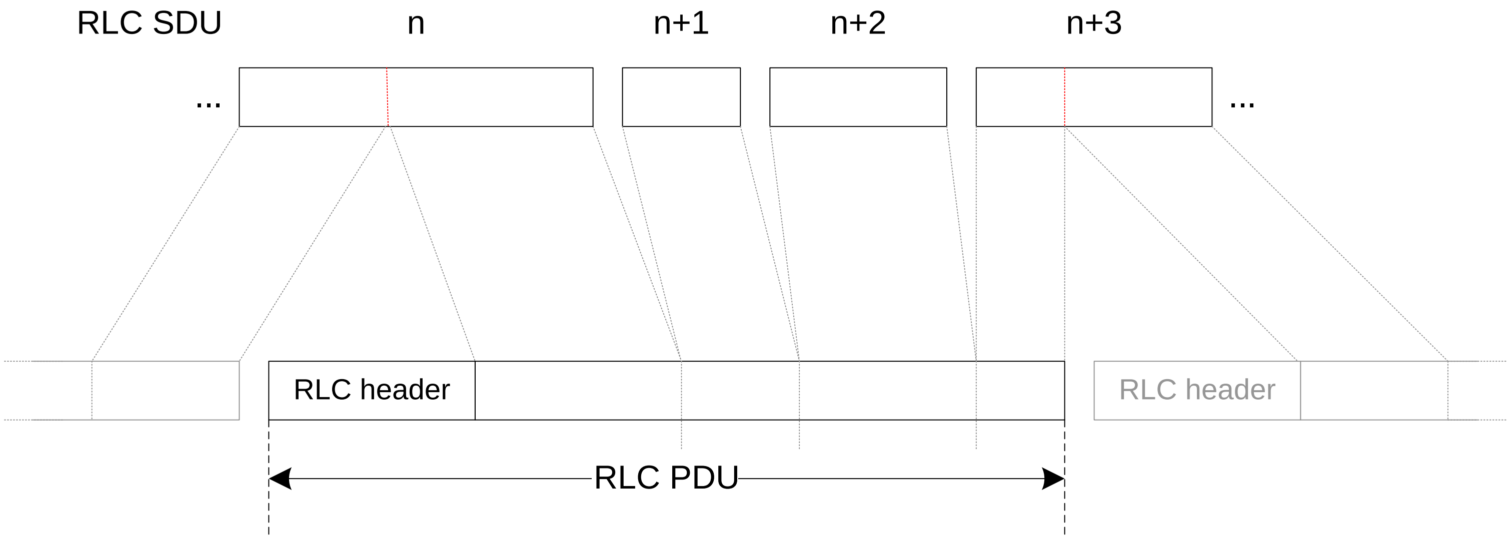
- The following connections exist
  - BCCH can be mapped to BCH
  - BCCH can be mapped to DL-SCH
  - BR-BCCH can be mapped to DL-SCH
  - PCCH can be mapped to PCH
  - CCCH can be mapped to DL-SCH
  - DCCH can be mapped to DL-SCH
  - DTCH can be mapped to DL-SCH
  - MTCH can be mapped to MCH
  - MCCH can be mapped to MCH
  - SC-MTCH can be mapped to DL-SCH
  - SC-MCCH can be mapped to DL-SCH

RLC Sublayer - 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)
- Reordering of RLC data PDUs (only for UM and AM data transfer)
- Duplicate detection (only for UM and AM data transfer)
- Protocol error detection (only for AM data transfer)
- RLC SDU discard (only for UM and AM data transfer)
- RLC re-establishment, as defined in TS 24.301

RLC PDU Structure



- 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

PDCP Sublayer - Services and Functions

Except for NB-IoT, the main services and functions of the PDCP sublayer for the user plane include

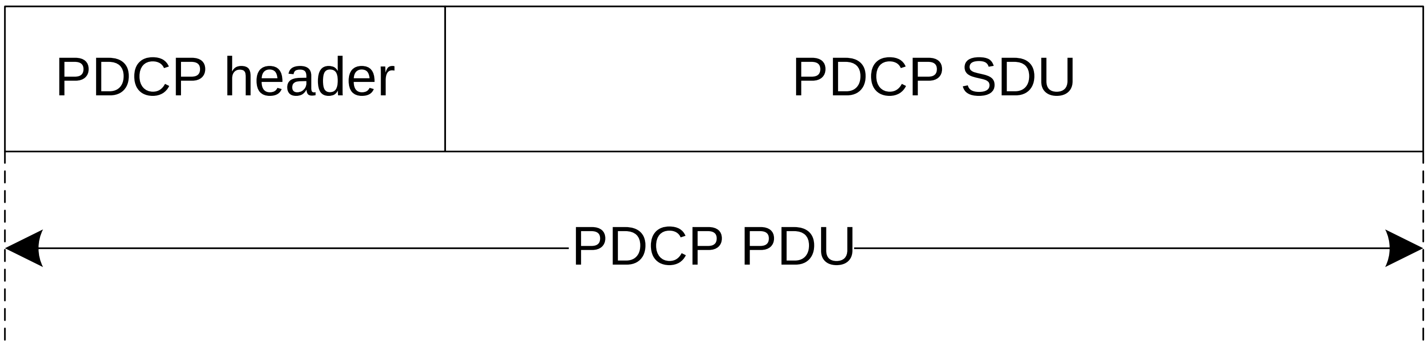
- Header compression and decompression: ROHC only
- Compression and decompression of uplink PDCP SDUs: DEFLATE based UDC only
- Transfer of user data
- In-sequence delivery of upper layer PDUs at PDCP re-establishment procedure for RLC AM
- For split bearers in DC (only support for RLC AM) and LWA bearers (only support for RLC AM and RLC UM): PDCP PDU routing for transmission and PDCP PDU reordering for reception
- Duplicate detection of lower layer SDUs at PDCP re-establishment procedure for RLC AM
- Retransmission of PDCP SDUs at handover and, for split bearers in DC and LWA, of PDCP PDUs at PDCP data-recovery procedure, for RLC AM
- Ciphering and deciphering
- Timer-based SDU discard in uplink
- Duplication of PDCP PDUs
- For PDCP duplication, reordering and duplicate detection at the receiver

PDCP Sublayer - Services and Functions (Cont.)

Except for NB-IoT, the main services and functions of the PDCP sublayer for the control plane also include

- Duplication of PDCP PDUs
- For PDCP duplication, reordering and duplicate detection at the receiver

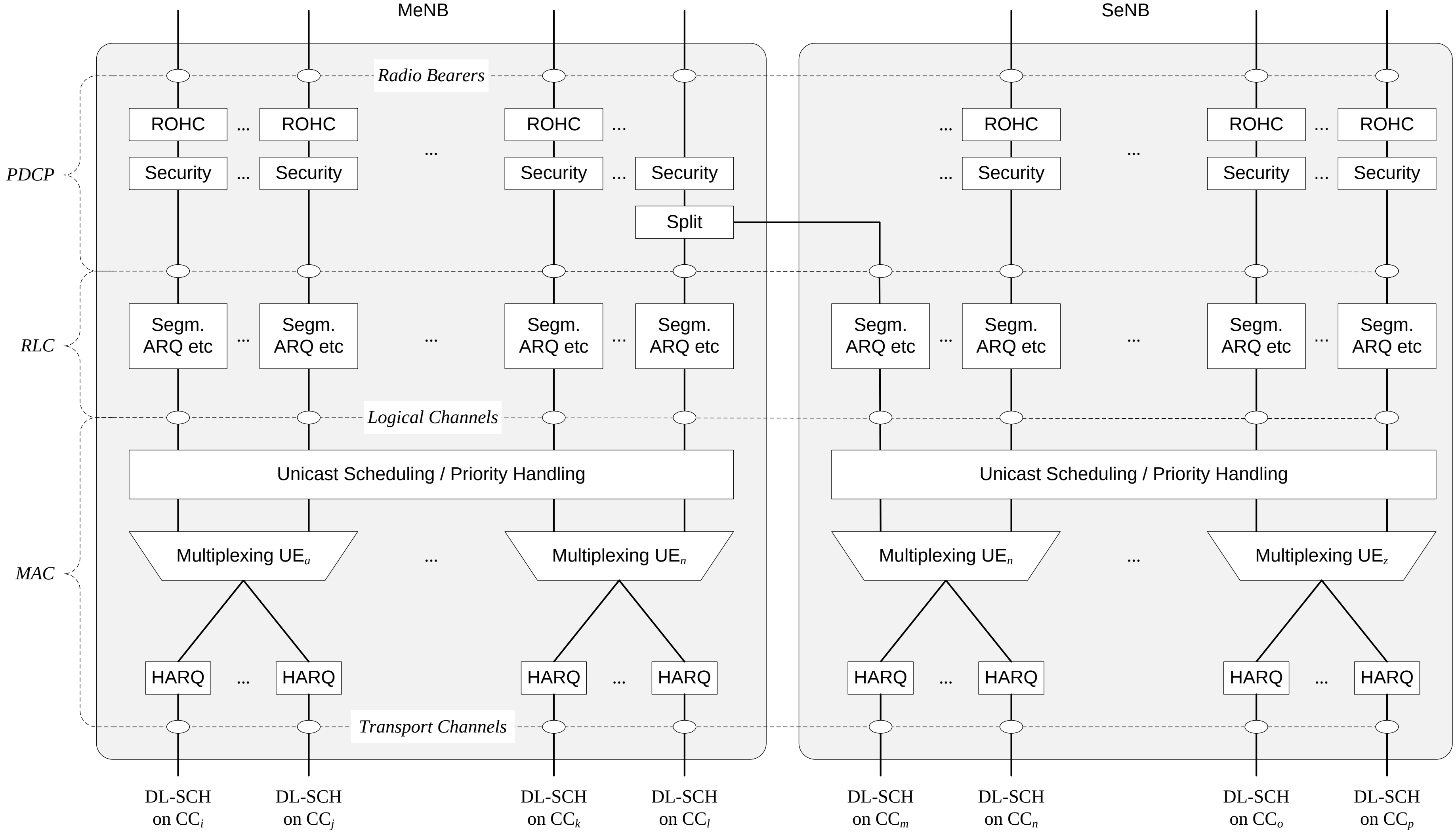
PDCP PDU Structure



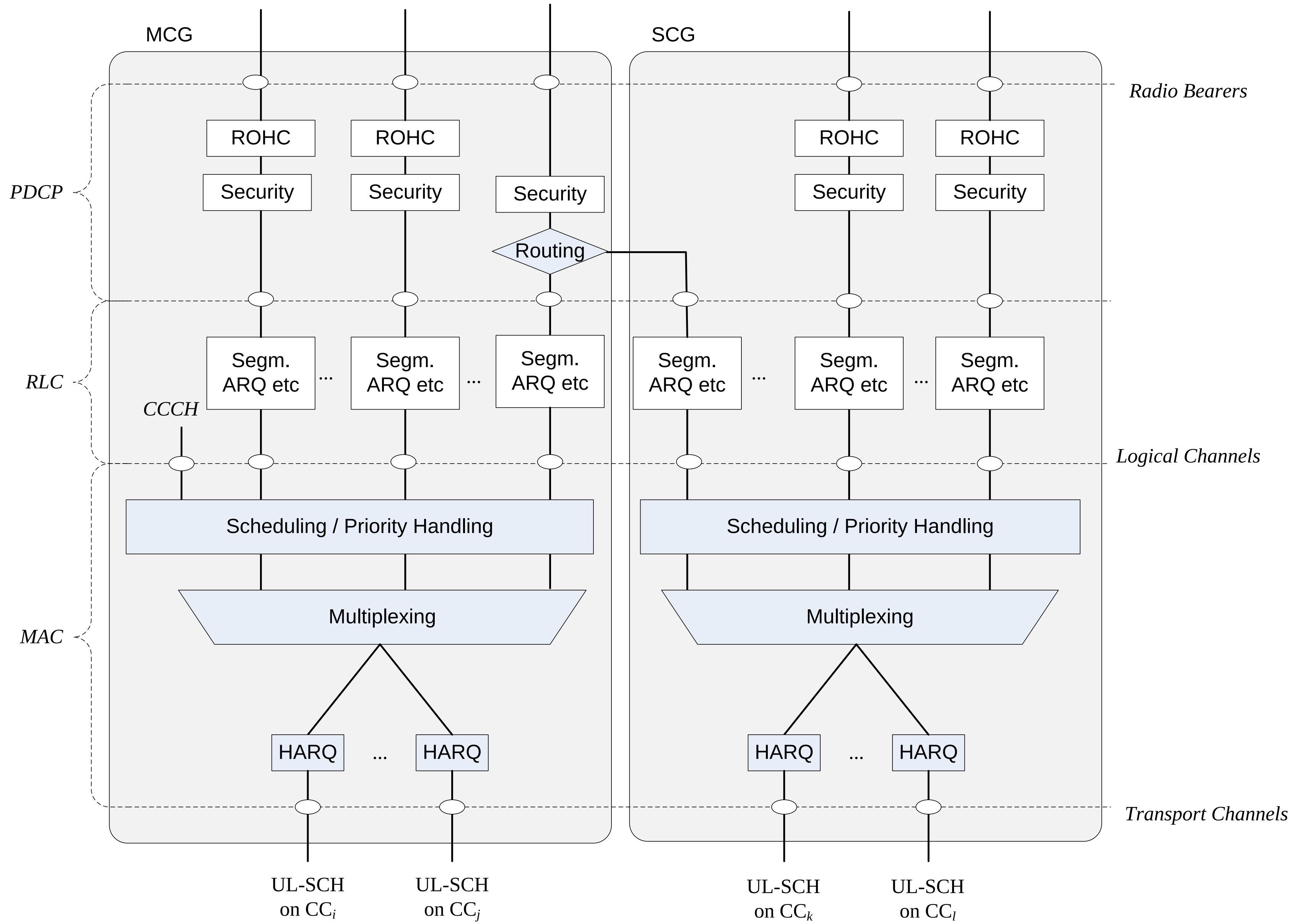
- The PDCP PDU structure for user plane data, where:
  - PDCP PDU and PDCP header are octet-aligned
  - PDCP header can be either 1 , 2 or 5 bytes long

The structures for control PDCP PDUs and for control plane PDCP data PDUs are specified in TS 36.323

Layer 2 Structure for DL with CA and DC Configured



Layer 2 Structure for UL with CA and DC Configured



RRC 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
- Notification and counting for MBMS services
- Establishment, configuration, maintenance and release of Radio Bearers for MBMS services
- QoS management functions
- UE measurement reporting and control of the reporting
- NAS direct message transfer to/from NAS from/to UE

RRC Protocol States & State Transitions

RRC uses the following states

- RRC_IDLE
- RRC_CONNECTED

E-UTRA connected to 5GC additionally supports RRC_INACTIVE state

- RRC_INACTIVE

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 (except for a UE that supports User Plane CIoT EPS optimizations where a context may be stored for the resume procedure)
- Sidelink communication transmission and reception
- Sidelink discovery announcement and monitoring
- V2X sidelink communication transmission and reception
- EDT

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
- Sidelink communication transmission and reception
- Sidelink discovery announcement and monitoring
- V2X sidelink communication transmission and reception
- 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

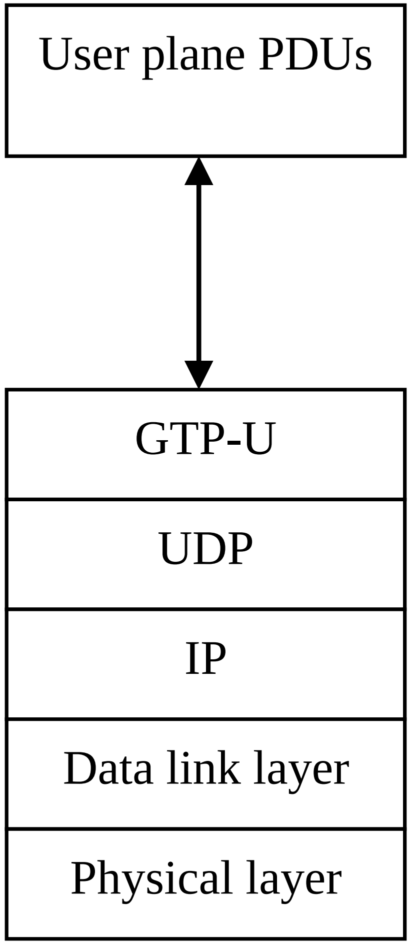
RRC_INACTIVE

- PLMN selection
- Broadcast of system information
- Cell re-selection mobility
- Monitors a Paging channel for CN paging and RAN paging
- RAN-based notification area (RNA) is configured by NG-RAN
- DRX for RAN paging configured by NG-RAN
- 5GC-NG-RAN connection (both C/U-planes) is established for UE
- The UE AS context is stored in NG-RAN and the UE
- NG-RAN knows the RNA which the UE belongs to

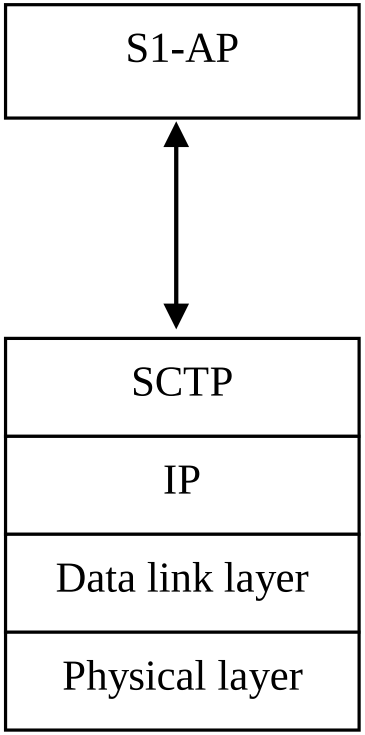
19. S1 Interface

- The S1 user plane interface (S1-U) is defined between the eNB and the S-GW
  - The S1-U interface provides non guaranteed delivery of user plane PDUs between the eNB and the S-GW
  - The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs between the eNB and the S-GW
- The S1 control plane interface (S1-MME) is defined between the eNB and the MME
  - The transport network layer is built on IP transport, similarly to the user plane but for the reliable transport of signalling messages SCTP is added on top of IP
  - The application layer signalling protocol is referred to as S1-AP (S1 Application Protocol)

S1 Interface User Plane (eNB - S-GW)



S1 Interface Control Plane (eNB-MME)



- The SCTP layer provides the guaranteed delivery
  - A single SCTP association per S1-MME interface instance shall be used with one pair of stream identifiers for S1-MME common procedures
    - Only a few pairs of stream identifiers should be used for S1-MME dedicated procedures
  - The communication context identifiers are conveyed in respective S1-AP messages
    - MME communication context identifiers that are assigned by the MME for S1-MME dedicated procedures and
    - eNB communication context identifiers that are assigned by the eNB for S1-MME dedicated procedures shall be used to distinguish UE specific S1-MME signalling transport bearers

Handling S1AP Broken Connection

If the S1 signalling transport layer notifies the S1AP layer that the signalling connection broke

- The MME
  - either locally changes the state of the UEs which used this signalling connection to the ECM-IDLE state as described in TS 23.401 and removes suspended UE Context data for UEs in ECM-IDLE which have used the S1 signalling connection before it was broken; or
  - keep UEs in ECM_CONNECTED and keep suspended UE Context data for UEs in ECM-IDLE which have used the S1 signalling connection before it was broken
- The eNB
  - either releases the RRC connection with those UEs and removes suspended UE Context data for UEs in RRC_IDLE which have used the S1 signalling connection before it was broken; or
  - keep UEs in RRC_CONNECTED and keep the suspended UE Context data for UEs in ECM-IDLE which have used the S1 signalling connection before it was broken

S1 Interface Functions

- E-RAB Service Management function
  - Setup, Modify, Release
- Mobility Functions for UEs in ECM-CONNECTED
  - Intra-LTE Handover
  - Inter-3GPP-RAT Handover
- S1 Paging function
- NAS Signalling Transport function
- LPPa Signalling Transport function
- S1-interface management functions
  - Error indication
  - Reset
- Network Sharing Function
- Roaming and Access Restriction Support function
- NAS Node Selection Function

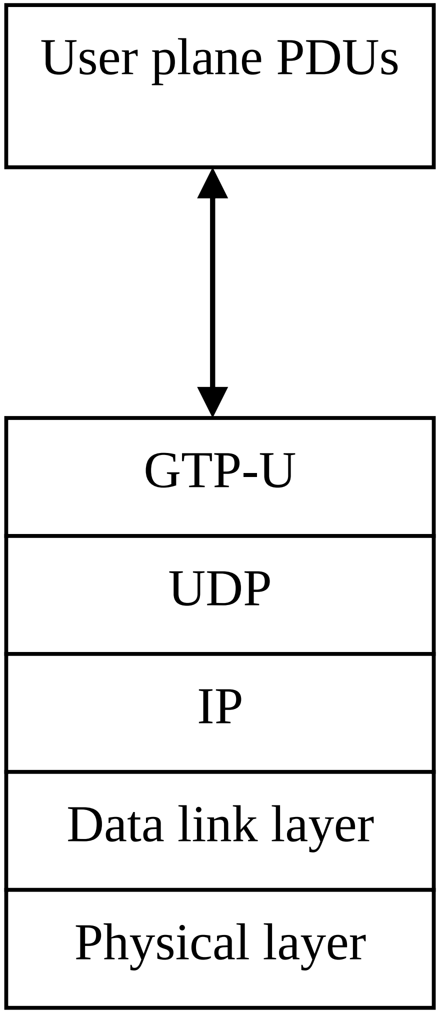
S1 Interface Functions (Cont.)

- Initial Context Setup Function
- UE Context Modification Function
- UE Context Resume Function
- MME Load balancing Function
- Location Reporting Function
- PWS (which includes ETWS and CMAS) Message Transmission Function
- Overload function
- RAN Information Management Function
- Configuration Transfer Function
- S1 CDMA2000 Tunnelling function
- Trace function
- UE Radio Capability Match
- Retrieve UE Information Function
- UE Information Transfer Function
- Report of Secondary RAT data volumes Function

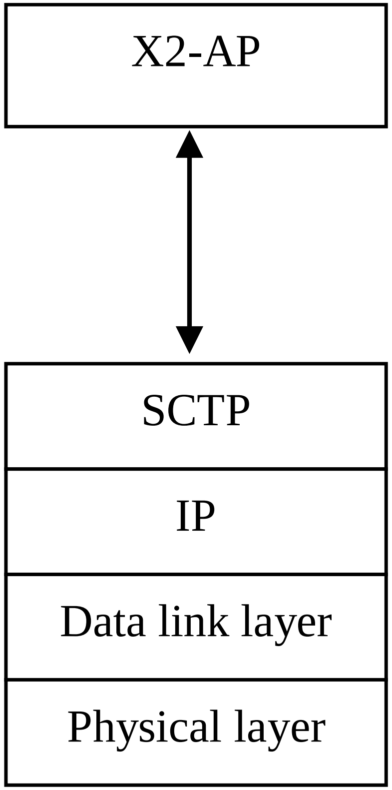
20. X2 Interface

- The X2 user plane interface (X2-U) is defined between eNBs
  - The X2-U interface protocol stack is identical to the S1-U protocol stack
  - The X2-U interface provides non guaranteed delivery of user plane PDUs
  - The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs
  - For DC, if X2-U user data bearers are associated with E-RABs for which the split bearer option is configured, GTP-U conveys PDCP PDUs in uplink and downlink and a RAN Container containing flow control information
    - The RAN Container is carried in the "RAN Container" field of the GTP-U extension header
- The X2 control plane interface (X2-CP) is defined between two neighbour eNBs
  - The transport network layer is built on SCTP on top of IP
  - The application layer signalling protocol is referred to as X2-AP (X2 Application Protocol)

X2 Interface User Plane (eNB-eNB)



X2 Interface Control Plane



- Two identifiers shall be used to distinguish UE specific X2-C signalling transport bearers
  - Source-eNB communication context identifiers that are assigned by the source-eNB for X2-C dedicated procedures, and
  - Target-eNB communication context identifiers that are assigned by the target-eNB for X2-C dedicated procedures

24. Support for 5GC

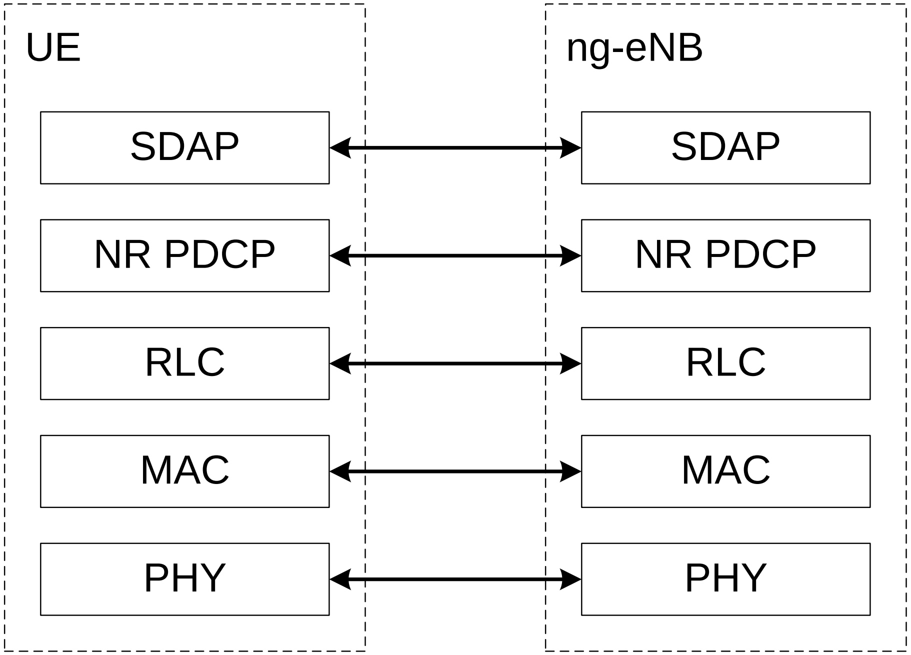
- The E-UTRA connected to 5GC is supported as part of NG-RAN
  – The E-UTRA can be connected to both EPC and 5GC
- The overall architecture of E-UTRA connected to 5GC as part of NG-RAN is described in TS 38.300, where the term "ng-eNB" is used for E-UTRA connected to 5GC
  – In this specification the term "eNB" is used for both cases unless there is a specific need to disambiguate between eNB and ng-eNB

E-UTRA Functions for 5GC

E-UTRA connected to 5GC supports the following functions

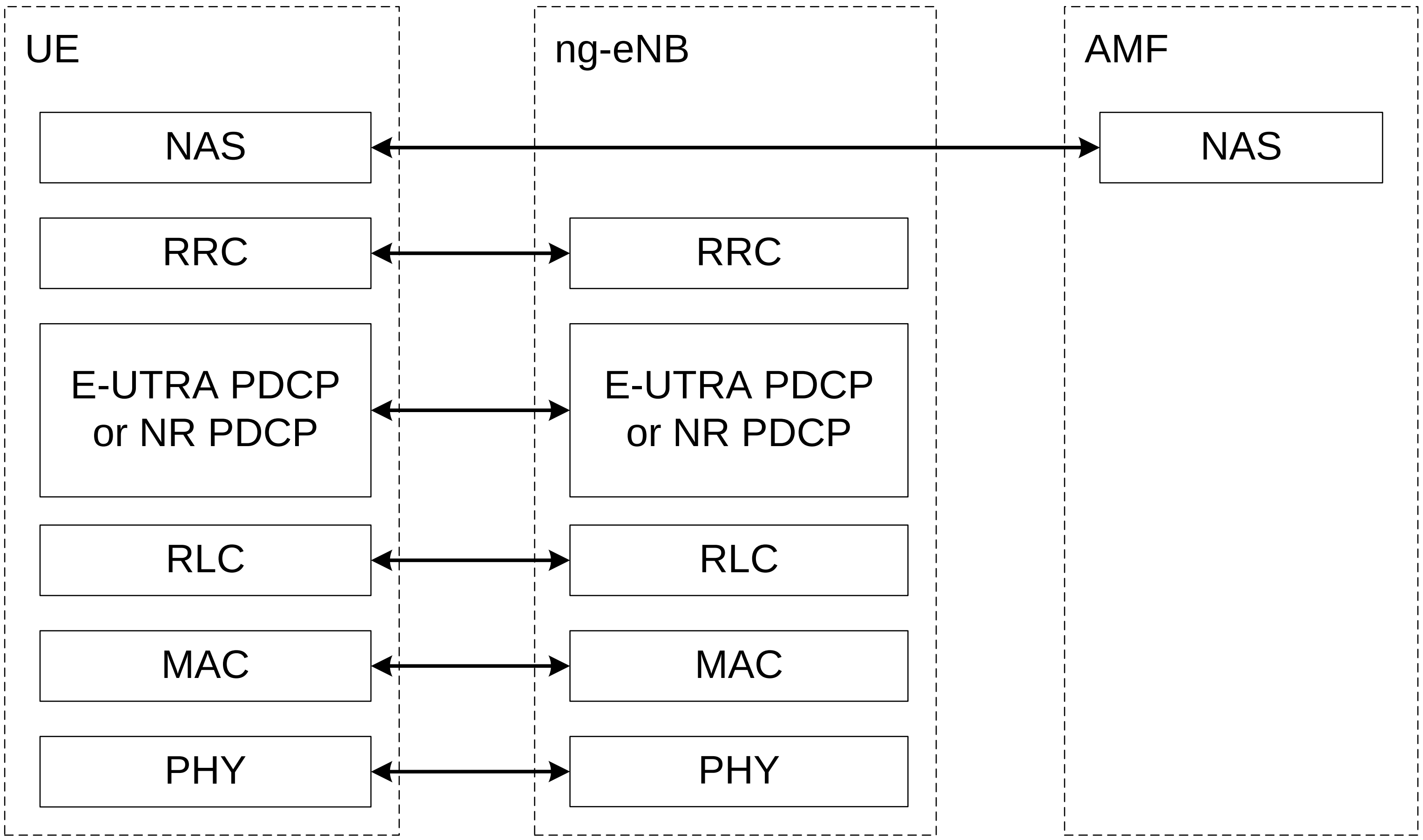
- 5G NAS message transport (TS 36.300 Subclause 7.3)
- 5G security framework (TS 38.300)
  - Except that data integrity protection is not supported
- Access Control (TS 38.300)
- Flow-based QoS (TS 38.300)
- Network slicing (TS 38.300)
- SDAP (TS 37.324)
- NR PDCP (TS 38.323)
- Support of UEs in RRC_INACTIVE state

User Plane Protocol Stack for E-UTRA-to-5GC



- The protocol stack for the user plane, where SDAP, NR PDCP, RLC and MAC sublayers perform the functions listed in TS 38.300 subclause 6.5, subclause 6.4, subclause 6.3, and subclause 6.2 respectively

Control Plane Protocol Stack for E-UTRA-to-5GC



Control Plane Protocol Stack for E-UTRA-to-5GC (Cont.)

- E-UTRA PDCP sublayer (terminated in ng-eNB on the network side) performs the functions listed for the control plane in subclause 6.3, and NR PDCP sublayer (terminated in ng-eNB on the network side) performs the functions listed for the control plane in subclause 6.4 of 3GPP TS 38.300
  - At initial RRC connection establishment SRB1 uses E-UTRA PDCP
  - After initial RRC connection establishment, SRB1 is reconfigured implicitly to use NR PDCP after the transmission of the RRCConnectionSetupComplete message
  - SRB2 always uses NR PDCP
- RLC and MAC sublayers (terminated in ng-eNB on the network side) perform the functions listed in subclause 6.2 and 6.1
- RRC (terminated in ng-eNB on the network side) performs the functions listed in subclause 7
- NAS control protocol (terminated in AMF on the network side) performs the functions listed in TS 23.501, for instance: authentication, mobility management, security control

Layer 2 of E-UTRA-to-5GC

The layer 2 of E-UTRA connected to 5GC is split into the following sublayers:

- Medium Access Control (MAC)
  - The physical layer offers to the MAC sublayer transport channels, see subclause 5
  - The MAC sublayer offers to the RLC sublayer logical channels, see subclause 6.1
- Radio Link Control (RLC)
  - The RLC sublayer offers to the PDCP sublayer RLC channels, see subclause 6.2
- Packet Data Convergence Protocol (PDCP)
  - The E-UTRA PDCP sublayer offers to the RRC sublayer signalling radio bearers (SRB) see subclause 6.3
  - The NR PDCP sublayer offers to the SDAP sublayer data radio bearers, and offers to the RRC sublayer signalling radio bearers, see 3GPP TS 38.323
- Service Data Adaptation Protocol (SDAP)
  - The SDAP sublayer offers to 5GC QoS flows, see 3GPP TS 37.324

CN Selection of E-UTRA-to-5GC

- For a cell that provides E-UTRA connectivity to both 5GC and EPC within a PLMN, the UE upper layer performs CN selection between EPC and 5GC
- The UE AS layer indicates available CN type(s) to upper layers for CN type selection
- The UE NAS layer indicates selected CN type (if available) with selected PLMN during PLMN selection procedure, as defined in 3GPP TS 36.304

Mobility of E-UTRA-to-5GC

- The procedure for the new mobility scenario intra-EUTRA inter-systerm Handover (i.e., handover between E-UTRA connected to 5GC and E-UTRA connected to EPC) is described in section 10.2.2c
- The core network is changed during the procedure, as defined in TS 23.502
- Inter-RAT handover to/from GERAN/UTRAN/CDMA2000 and cell change order to GERAN with NACC are not supported, and CS fallback described in subclause 10.2.5 is not applied except for the functionality of release with redirection to GERAN/UTRAN
- The following mobility procedures are supported
  - RRC Connection Release with Redirection to GERAN / UTRAN / CDMA2000 / EUTRAN
  - Cell Change Order to GERAN without NACC
- When the UE is connected to E-UTRA/5GC, inter system fallback towards E-UTRAN is performed when 5GC does not support emergency services, voice services, for load balancing etc
  - Depending on factors such as CN interface availability, network configuration and radio conditions, the fallback procedure results in either CONNECTED state mobility (handover procedure) or IDLE state mobility (redirection)
  - see TS 23.501 and TS 36.331

Mobility of E-UTRA-to-5GC (Cont.)

- In the N2 signalling procedure, the AMF based on support for emergency services, voice service, any other services or for load balancing etc, may indicate the target CN type as EPC or 5GC to the ng-eNB node
  - When the target CN type is received by ng-eNB, the target CN type is also conveyed to the UE in RRC Connection Release Message
- The mobility in RRC_INACTIVE is described in section 10.1.9
- For E-UTRA connected to 5GC, in RRC_IDLE the UE monitors the PCCH for CN-initiated paging information, in RRC_INACTIVE the UE monitors the PCCH for RAN-initiated and CN-initiated paging information
  - NG-RAN and 5GC paging occasions overlap and the same paging mechanism is used in NG-RAN and in 5GC
    - The extended DRX (eDRX) is not used for E-UTRA connected to 5GC

Slicing and Access Control for E-UTRA-to-5GC

- Slicing
  - NG-RAN supports network slicing
  - The details of network slicing are specified in TS 23.501 and clause 16.3 of TS 38.300
- Access Control
  - E-UTRA connected to 5GC supports unified access control functionality. The details of unified access control are defined in TS 38.300
  - For E-UTRA connected to both EPC and 5GC, E-UTRAN broadcasts the access control information associated with EPC and 5GC separately and the UE AS uses the access control information associated with the core network type selected by NAS

Summary

- 3GPP 4G / LTE-A are introduced
  - LTE Core Network: EPC
  - LTE Radio Access Network: E-UTRAN
  - Connectivity among eNodeBs: The X2 Interface
- Further details of E-UTRAN are introduced based on TS 36.300
  - Overall architecture
  - Physical Layer for E-UTRA
  - Layer 2
  - RRC
  - S1 Interface
  - X2 Interface
  - Support for 5GC