LTE – 4G Mobile Broadband Standard

Based on:

- 3GPP specifications
- Research paper: Anna Larmo, Magnus Lindström, Michael Meyer, Ghyslain Pelletier, Johan Torsner, and Henning Wiemann, Ericsson Research: *The **LTE Link-Layer** Design,* IEEE Communications Magazine, April 2009. pp. 52-59
- Material available from the Internet
- C. Beard & W. Stallings (2016), “ Wireless Communication Networks and Systems”, Chapter 14 - 4G Systems and LTE-Advanced

Learning Outcomes

- Describe and revise the basic facts related to three coexisting technologies: GSM/EDGE, UMTS/HSPA, LTE
- Understand LTE architecture: EPC and E-UTRAN principles and functionalities at link-layer
  - UE and eNB
  - Serving Gateway S-GW
  - Packet Delivery Network PDN-GW
  - MME – Mobility Management Entity

Revision: three generations of mobile networks

- 2G systems: GSM/EDGE
- 3G UMTS systems: HSPA (High Speed Packet Access)
- 4G systems: LTE/LTE-A – Long Term Evolution (Advanced)

The above systems:

- have different **Radio interfaces**, and
- share components of **Core Networks** and **Service architecture**
- to allow exchange of basic **voice and SMS services**

See the general architecture of the PLMN – Public Land Mobile Network

Purpose, Motivation , and Approach to 4G

According ITU, five minimum requirements of 4G are:

- Be based on all –IP packet switched network.
- Support peak data rate of up to approximately – 100 Mbps for high mobility mobile access and 1 Gbps for low mobility access (e.g local wireless access)
- Dynamically share and use the network resources to support more simultaneous users per cell.
- Support smooth handovers across heterogeneous networks, including 2G and 3G networks, small cells such as picocells, femtocells, and relays, and WLANs.
- Support high quality of service (QoS) for next-generation multimedia applications

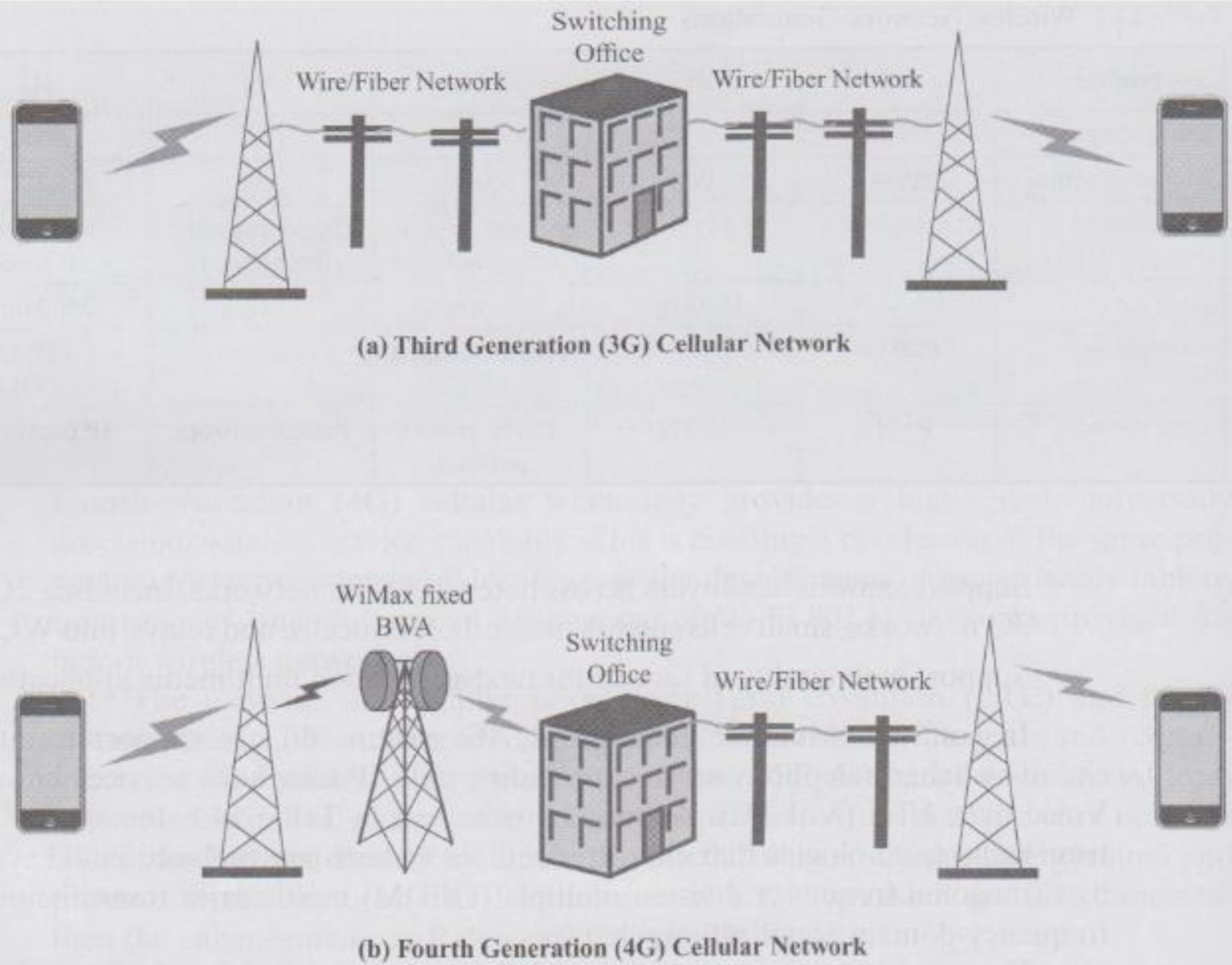


Figure 14.1 Third versus Fourth Generation Cellular Networks

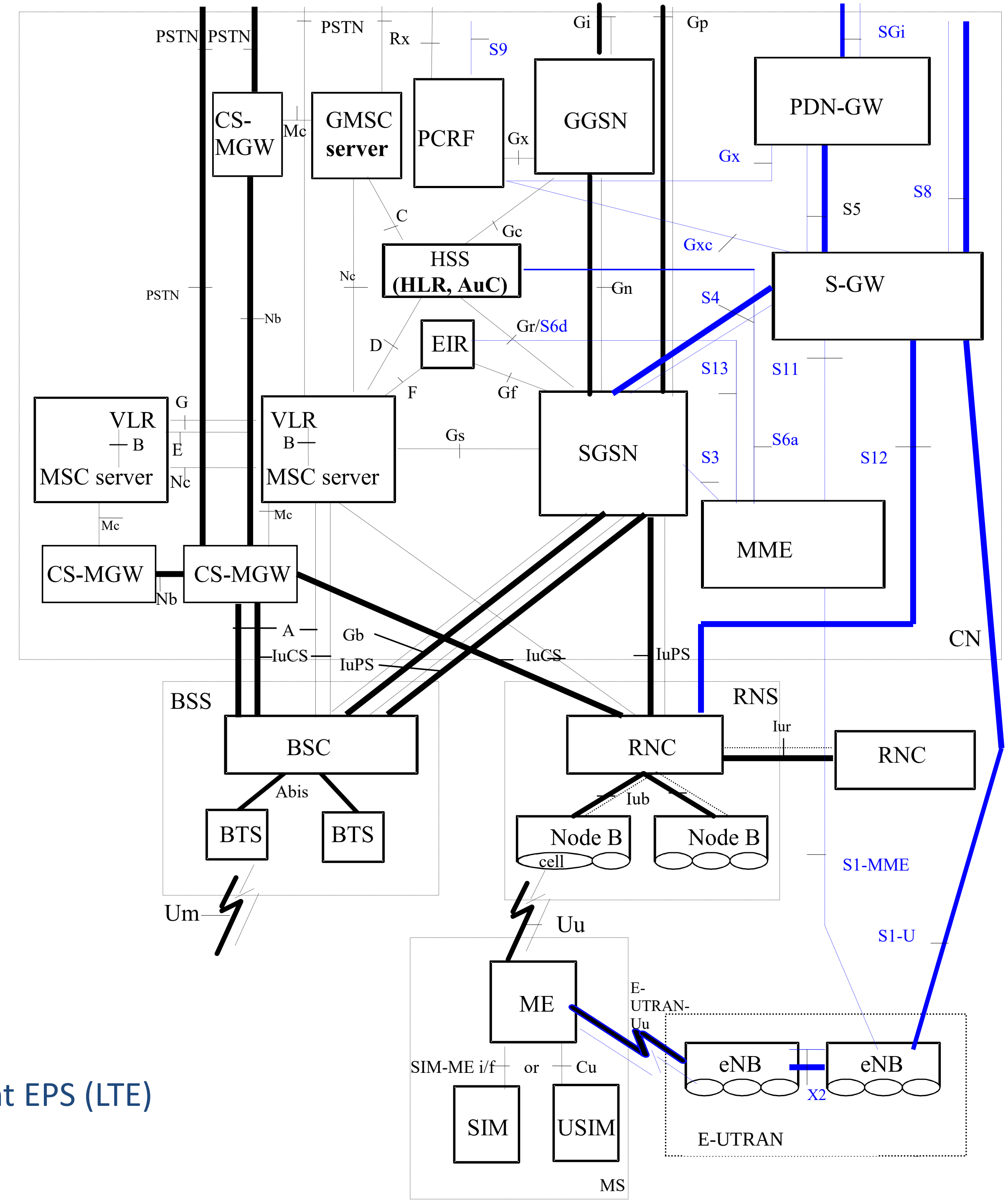
Figure 1b: Basic Configuration of a **3GPP Access PLMN** supporting CS and PS services (using GPRS and EPS) and interfaces

Identify: (local pdf)

- CN the core network
- BSS – the Base Station System (GSM)
- RNS aka UTRAN – the Radio Network System (UMTS)
- E-UTRAN – LTE Evolved Universal Terrestrial Radio Access Network
- MS – Mobile Station

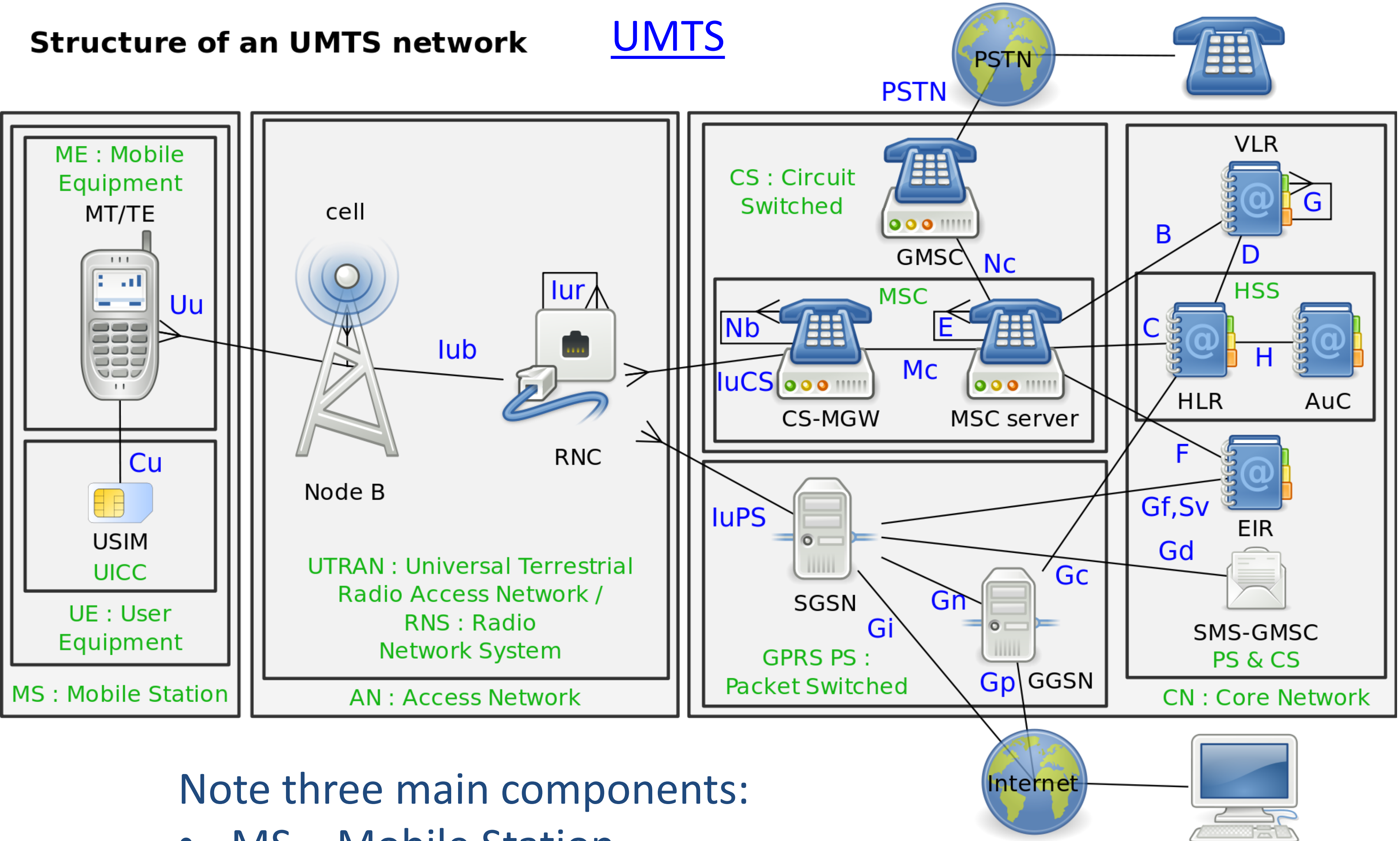
Note:

- Interfaces
- How the components of PLMN are shared between the three generations



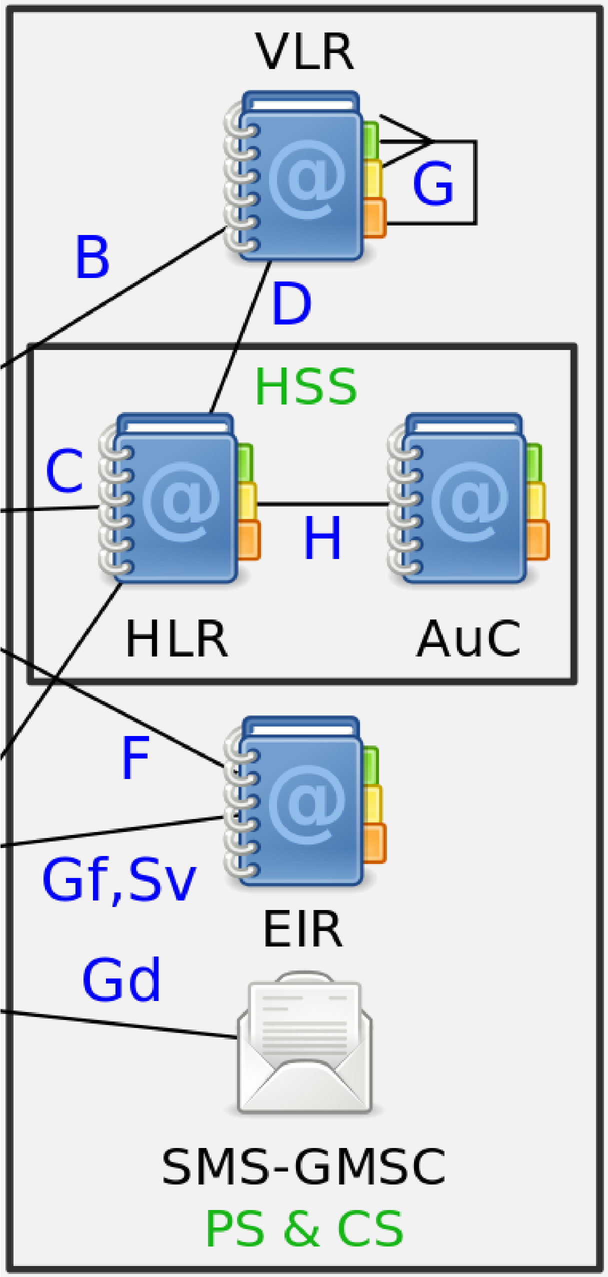
NOTE: The interfaces in blue represent EPS (LTE) functions and reference points.

Structure of an UMTS network



Note three main components:

- MS – Mobile Station
- AN – Access Network
- CN – Core Network



CN : Core Network

Core network servers and databases

HSS – Home Subscriber Server operates with two fundamental databases:

- **HLR** – Home Location Register
- **AuC** – Authentication Centre database

Two other fundamental databases are:

- **VLR** – Visitor Location Register
- **EIR** – Equipment Identity Register

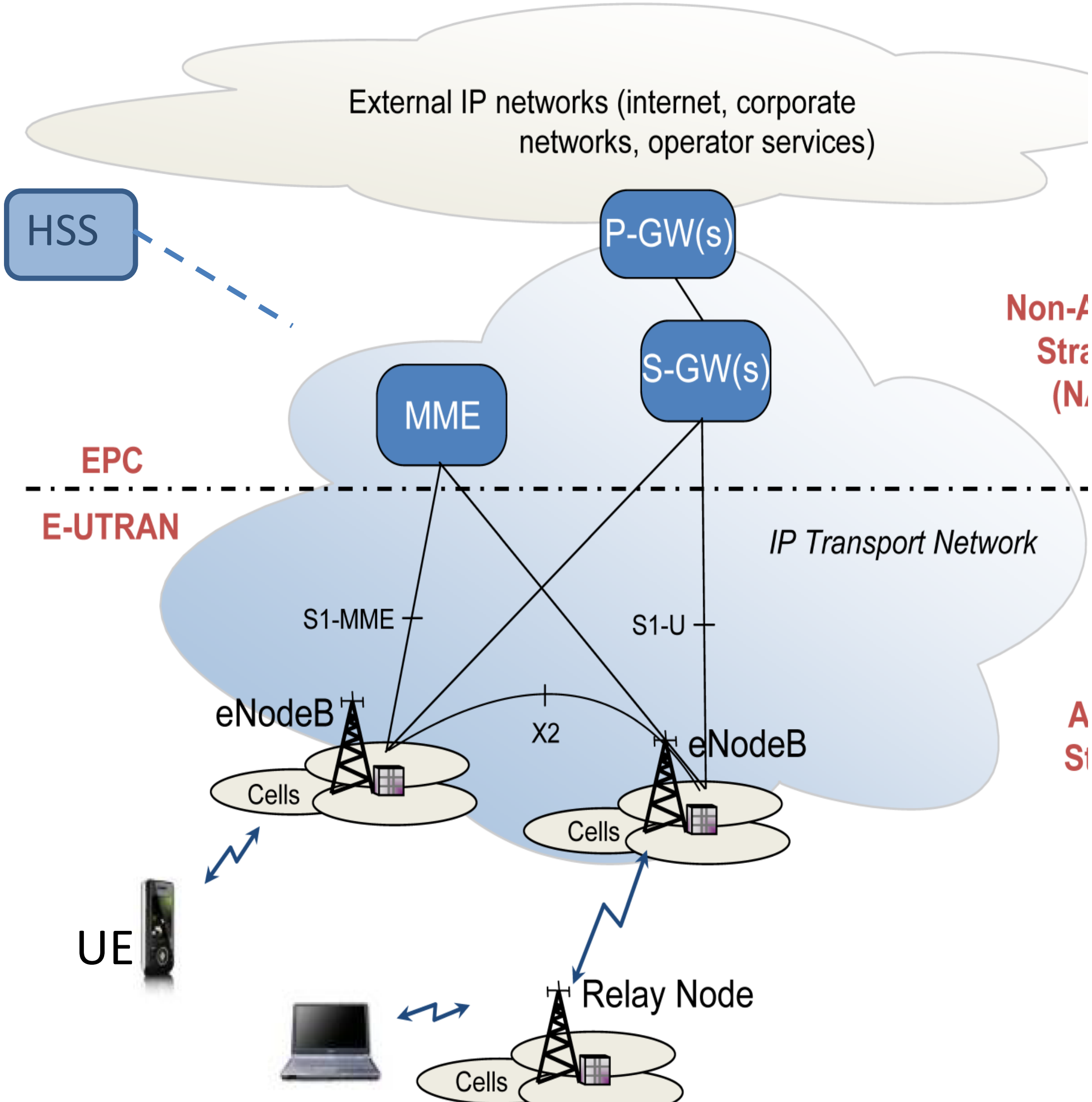
We will discuss details of the databases in the next lecture

4G Networks: LTE Long Term Evolution

- LTE (3GPP Release 8 – 2008) and LTE-Advanced (3GPP Release 10 – 2011) are new mobile communication standards evolved from GSM/EDGE and UMTS/HSPA network technologies.
- LTE-A targets the peak data rates of 1Gb/s using a long list of advanced technologies (e.g., OFDM, MIMO, …) in a full-duplex modes (FDD and TDD – Frequency/Time Division Duplexing)
- LTE is an **all-IP packet-based** network with the protocol stack being:
- L1 (Layer 1) → L2 → IP → {TCP, UTP, RTP} → applications

LTE: EPC + E-UTRAN architecture (1)

Evolved Packet Core + Evolved Universal Terrestrial Radio Access Network



- Flat all-IP multi-access core network
- Enhanced NodeB (**eNB**) (former base station/NodeB)
- **UE** – User Equipment
- **MME** – Mobility Management Entity (Control Plane)
- **S-GW** – Serving Gateway (User Plane)
- **P-GW** – Packet Delivery Network Gateway
- **HSS** – Home Subscriber Server

LTE: EPC + E-UTRAN architecture (2)

Evolved Packet Core + Evolved Universal Terrestrial Radio Access Network

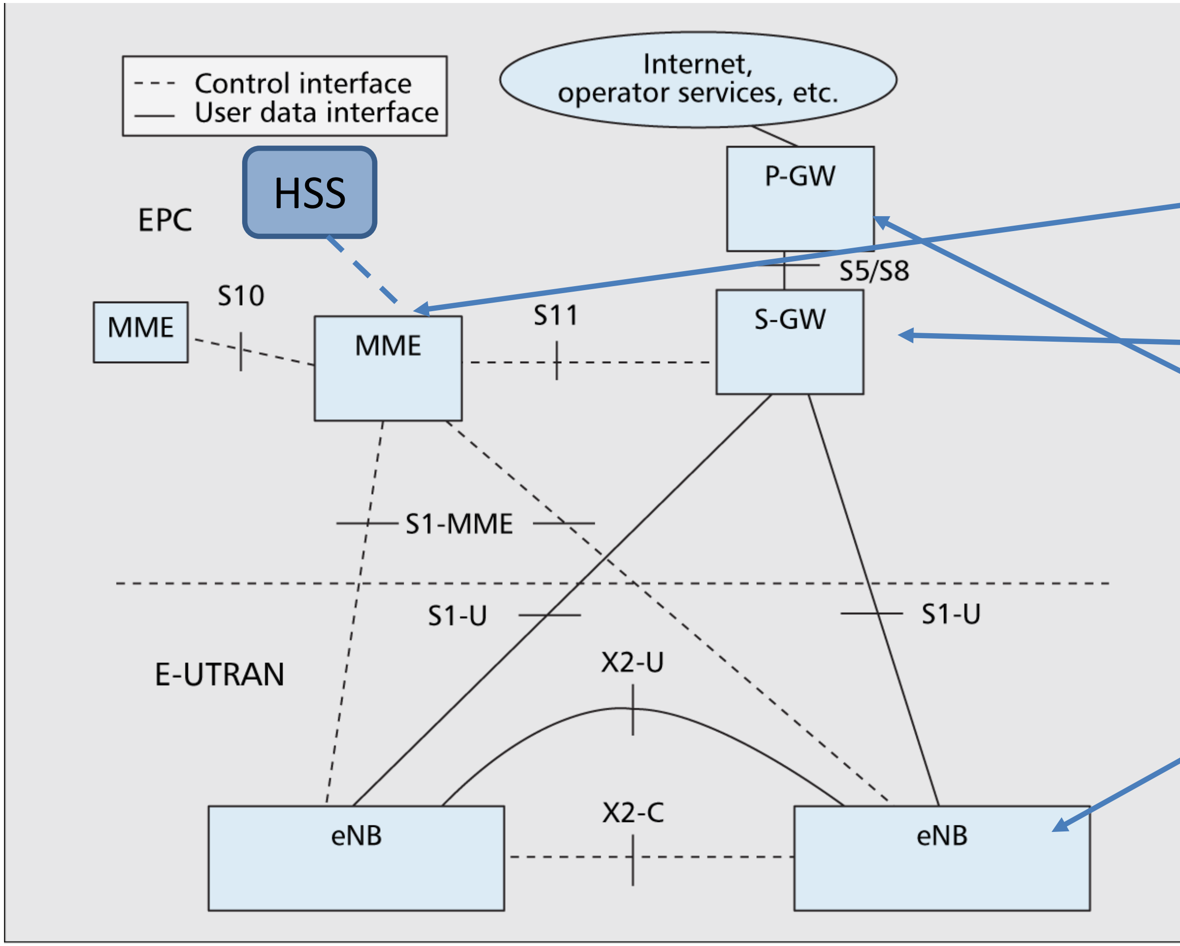


Figure 1. *Overview of the EPC/LTE architecture.*

The **EPC** consists of:

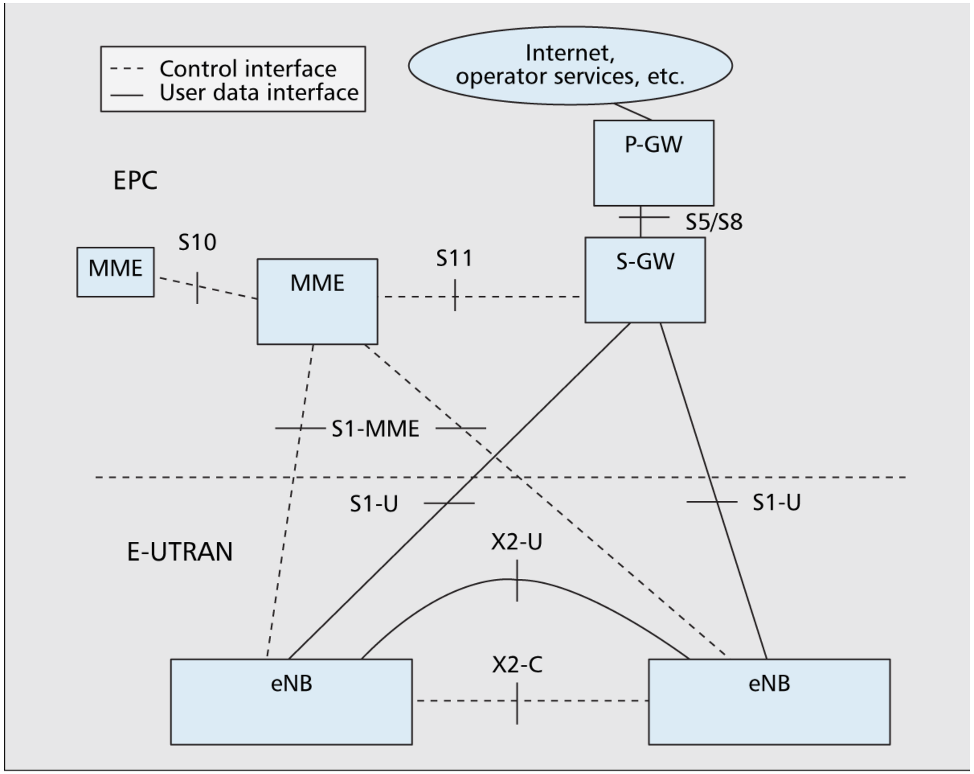
- one control-plane node, called a **mobility management entity** (MME),
- two user-plane nodes:
  - **serving gateway** (S-GW)
  - **packet-data network gateway** (P-GW, PDN-GW).

The **E-UTRAN** radio-access network consists of:

- the **base stations** - enhanced Node B (eNB), connected to:
- each other through the X2 interface
- the EPC through the S1 interface.

HSS – Home Subscriber Server

EPC/LTE Architecture (3)



■ **Figure 1.** *Overview of the EPC/LTE architecture.*

- The EPC architecture: user-plane nodes (eNB and S/P-GW), is simpler than the previous (GPS, UMTS) architectures (e.g. no RNC as in UMTS))
- **Handovers** between eNBs are handled through packet forwarding over the X2 interface. (We will discuss it later.)

Serving Gateway S-GW

Some of the functions of the Serving GW include:

- Packet routing and forwarding
- the local Mobility Anchor point for inter-eNB **handover**
- Transport level packet marking in the uplink and the downlink
- Event reporting to the PCRF (Policy and Charging Rules Function)

Packet Delivery Network GW

PDN GW functions include:

- UE (User Equipment) IP address allocation;
- Filtering user packets (by e.g. deep packet inspection);
- Transport level packet marking in the uplink (UL) and downlink (DL)
- UL and DL service level charging, gating control, rate enforcement
- DHCPv4 and DHCPv6 (client and server) functions;

MME – Mobility Management Entity

MME is the control plane entity within EPS supporting the Mobility Management functions including:

- NAS (Non-Access-Stratum) signalling and security
- Inter CN (Core Network) node signalling for mobility between 3GPP access networks
- Selection of the PDN GW and Serving GW
- Selection of the SGSN (Serving GPRS Support Node) for handovers to 2G or 3G 3GPP access networks
- Roaming
- Authentication of UE (User Equipment)

The Home Subscriber Server (HSS) 1

- The HSS is the master database for a given user.
- It is the entity containing the subscription-related information to support the network entities actually handling calls/sessions.
- A Home Network may contain one or several HSSs: it depends on the number of mobile subscribers, on the capacity of the equipment and on the organisation of the network.
- As an example, the HSS provides support to the call control servers in order to complete the routing/roaming procedures by solving authentication, authorisation, naming/addressing resolution, location dependencies, etc.
- The HSS is responsible for holding the following user related information:
  - User Identification, Numbering and Addressing information;
  - User Security information: Network access control information for authentication and authorization;
  - User Location information at inter-system level: the HSS supports the user registration, and stores inter-system location information, etc.;
  - User profile information.
- The HSS also generates User Security information for mutual authentication, communication integrity check and ciphering.
- Based on this information, the HSS also is responsible to support the call control and session management entities of the different Domains and Subsystems, e.g.: MSC Server, GMSC Server, SGSN GGSN

The Home Subscriber Server (HSS) 2

- The HSS may integrate heterogeneous information, and enable enhanced features in the core network to be offered to the application & services domain, at the same time hiding the heterogeneity.
- The HSS consists of the following functionalities:
  - The subset of the HLR/AuC functionality required by the PS Domain (GPRS and EPC).
  - The subset of the HLR/AuC functionality required by the CS Domain, if it is desired to enable subscriber access to the CS Domain or to support roaming to legacy GSM/UMTS CS Domain networks.
  - IP multimedia functionality to provide support to control functions of the IM subsystem such as the CSCF. It is needed to enable subscriber usage of the IM CN subsystem services. This IP multimedia functionality is independent of the access network used to access the IM CN subsystem.

HSS Logical Functions 1

Mobility Management

- This function supports the user mobility through CS Domain, PS Domain and IM CN subsystem.

  Call and/or session establishment support
- The HSS supports the call and/or session establishment procedures in CS Domain, PS Domain and IM CN
- subsystem. For terminating traffic, it provides information on which call and/or session control entity currently
- hosts the user.

User security information generation

- The HSS generates user authentication, integrity and ciphering data for the CS and PS Domains and for the IM CN subsystem.

User security support

- The HSS supports the authentication procedures to access CS Domain, PS Domain and IM CN subsystem services by storing the generated data for authentication, integrity and ciphering and by providing these data to the appropriate entity in the CN (i.e. MSC/VLR, SGSN, MME, 3GPP AAA Server or CSCF).

User identification handling

- The HSS provides the appropriate relations among all the identifiers uniquely determining the user in the system: CS Domain, PS Domain and IM CN subsystem (e.g. IMSI and MSISDNs for CS Domain; IMSI, MSISDNs and IP addresses for PS Domain, private identity and public identities for IM CN subsystem).

Access authorisation

- The HSS authorises the user for mobile access when requested by the MSC/VLR, SGSN, MME, 3GPP AAA Server or CSCF, by checking that the user is allowed to roam to that visited network.

HSS Logical Functions 2

Service authorisation support

- The HSS provides basic authorisation for MT call/session establishment and service invocation. Besides, the HSS updates the appropriate serving entities (i.e., MSC/VLR, SGSN, MME, 3GPP AAA Server, CSCF) with the relevant information related to the services to be provided to the user.

Service Provisioning Support

- The HSS provides access to the service profile data for use within the CS Domain, PS Domain and/or IM CN subsystem. Application Services and CAMEL Services Support (for GERAN and UTRAN access).
- The HSS communicates with the SIP Application Server and the OSA-SCS to support Application Services in the IM CN subsystem.

Home Location Register (HLR) 1

- The HLR is consider to be a subset of the HSS and contains details of each mobile phone subscriber that is authorized to use the core network in GSM/UMTS environment
- The HLRs store details of every SIM card issued by the mobile phone operator.
- Each SIM has a unique identifier called an **IMSI** which is the primary key to each HLR record.
- The SIM also stores the **MSISDN**, which is the telephone number used by mobile phones to make and receive calls.

Home Location Register (HLR) 2

- The HLR data is stored for as long as a subscriber remains with the mobile phone operator. It also stores:
  - GSM services that the subscriber has requested or been given.
  - GPRS settings to allow the subscriber to access packet services.
  - Current location of subscriber
  - Call divert settings applicable for each associated MSISDN.
- The HLR is a system which directly receives and processes transactions and messages from elements in the GSM/UMTS network, for example,
- the location update messages received as mobile phones roam around.

Authentication Centre (AuC) database

- This database is also considered to be the subset of the HSS and is used for authentication activities of the system
- It holds the **authentication and encryption keys** for all the subscribers in both the home and visitor location registers.
- The centre controls access to user data as well as being used for authentication when a subscriber joins a network.
- Mobile transmission is **encrypted**, so it is private:
  - a cipher **A3** is used for authentication
  - a stream cipher **A5** is used to encrypt the transmission from subscriber to base transceiver.
  - However, the conversation is in the clear in the landline network.

Visitor Location Register (VLR)

Visitor Location Register (VLR) database: For **Circuit Switched** Services maintains information about subscribers that are currently physically in the region covered by the switching centre.

- The VLR records whether or not the subscriber is active and other parameters associated with the subscriber.
- For a call coming to the subscriber, the system uses the telephone number associated with the subscriber to identify the home switching centre of the subscriber.
- This switching centre can find in its HLR the switching centre in which the subscriber is currently physically located.
- For a call coming from the subscriber, the VLR is used to initiate the call.
- Even if the subscriber is in the area covered by its home switching centre, it is also represented in the switching centre's VLR, for consistency.

Equipment Identity Register (EIR) database

Equipment Identity Register (EIR) database is used in to keep track of the type of equipment that exists at the mobile station.

- It also plays a role in security:
  - blocking calls from stolen mobile stations
  - preventing use of the network by stations that have not been approved

Fundamentals of Physical Layer: Downlink

- The LTE **downlink** (DL) uses orthogonal frequency division multiplexing (OFDM)
  - robust to time dispersion of the radio channel.
  - a low-complexity receiver design,
- The multicarrier concept enables the operation of LTE in various system bandwidths up to 100 MHz by
  - adapting the number of subcarriers used to the allocated system bandwidth.
- OFDM supports **multi-user access:**
  - within a transmission interval, **subcarriers can be allocated to different users**.

Physical Layer: Uplink

- The LTE **uplink** employs a discrete Fourier transform (DFT)-spread OFDM (also denoted as single-carrier frequency division multiple access [**SC-FDMA**]).
- Compared to conventional OFDM, this OFDM variant provides an improved peak-to-average power ratio that enables more power-efficient terminals.

LTE Data Link Layer

- The link-layer protocols enhance the service to upper layers by increased reliability, security, and integrity.
- The link layer is responsible for the **multi-user medium access** and **scheduling**.
- The LTE link-layer must provide the required **reliability levels** and **delays** for Internet Protocol (IP) data flows for wide range of different services and data rates, e.g.:
- **Voice over IP** (VoIP) flows can tolerate delays on the order of 100ms and packet losses of up to 1% thanks to state-of-the-art voice codecs.
- **TCP file downloads requires** low bandwidth-delay products.
  - Downloads at very high data rates (e.g., 100 Mb/s) require even lower delays and are more sensitive to IP packet losses than VoIP traffic.
  - Required loss rates is on the order of 10^{-5} to 10^{-6}.

User Plane Protocol Stack – Link Layer

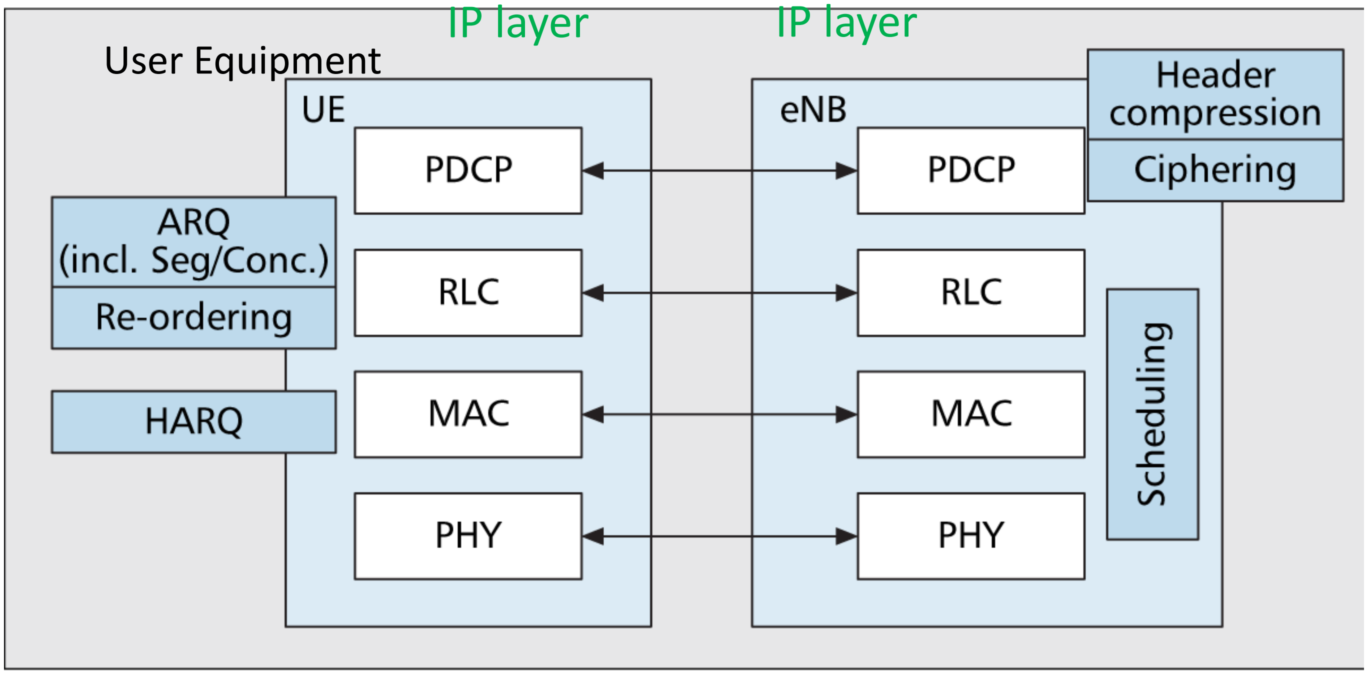


Figure 2. *User plane protocol stack.*

The LTE link layer consists of three sublayers:

- The Packet Data Convergence Protocol (PDCP)
- The radio link control (RLC)
- The medium access control (MAC)

PDCP is responsible for IP header compression and ciphering.

- Supports lossless mobility in case of inter-eNB handovers
- Provides **data integrity protection** to higher layer protocols.

RLC comprises: **ARQ** (Automatic Repeat reQest) functionality and

- supports data segmentation and concatenation

MAC provides **HARQ** (Hybrid ARQ) and is responsible for

- medium access control
- scheduling operation and random access.

Peer sublayers in UE and eNB are logically connected.

Data Flow Through L2 Protocol Stack

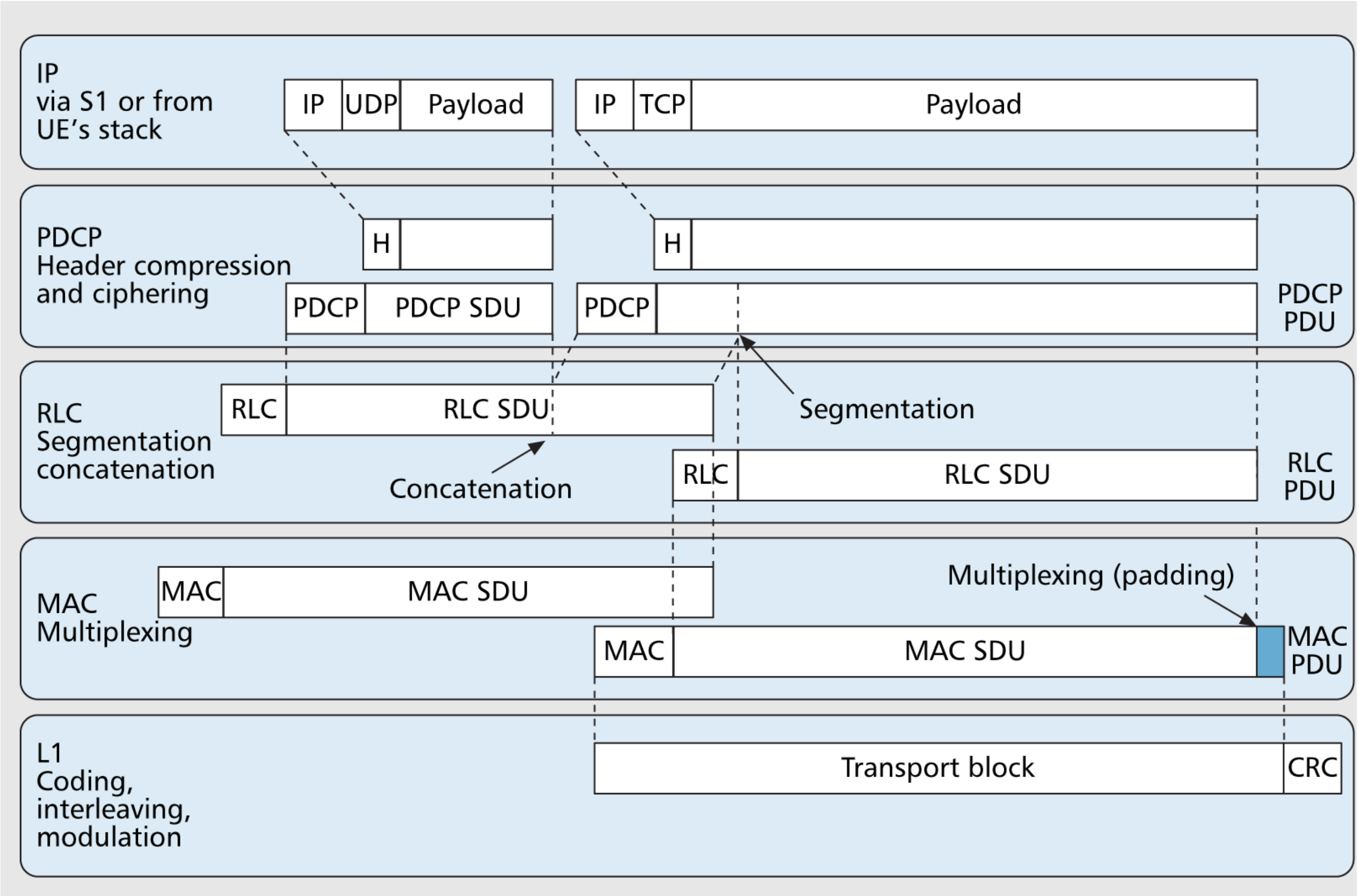
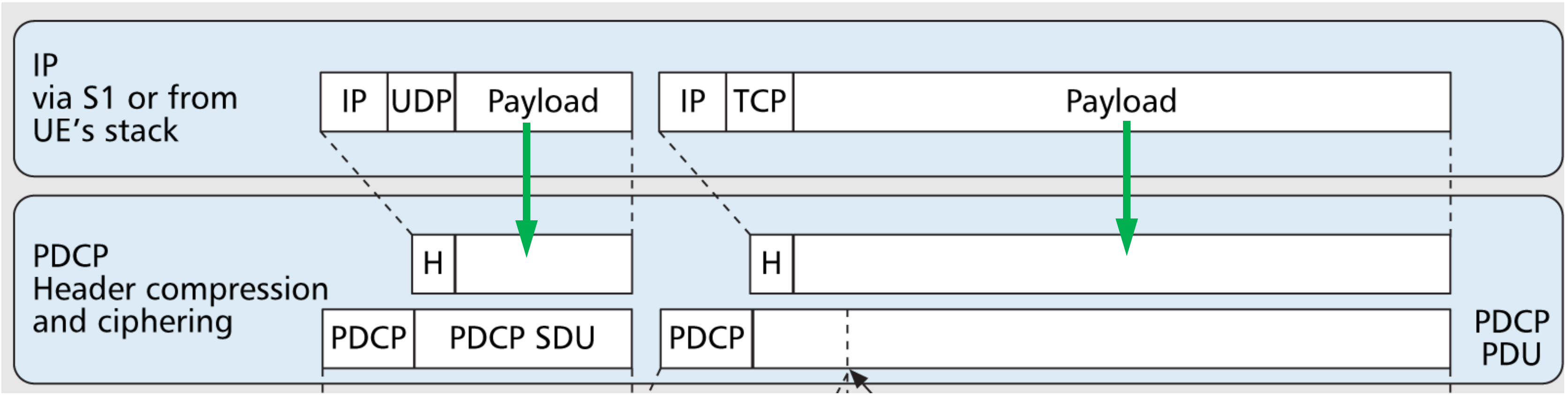


Figure 3. *Illustration of data flow through L2 protocol stack.*

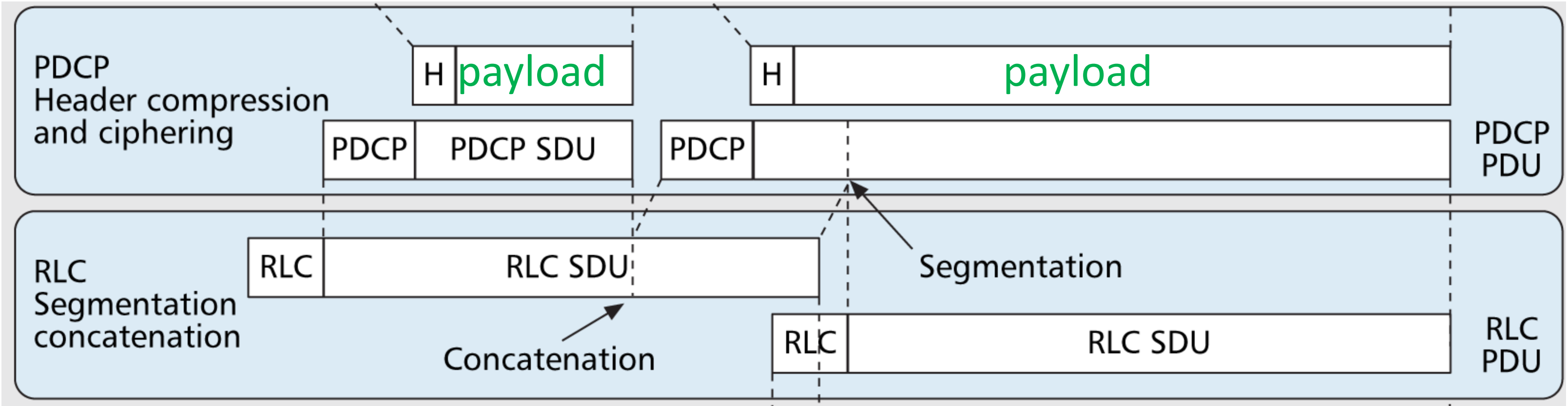
The data flow of an IP packet through the link-layer protocols down to the physical layer (L1). The figure shows that each protocol sublayer adds its own protocol header to the data units.

From the IP layer to the PDCP sublayer



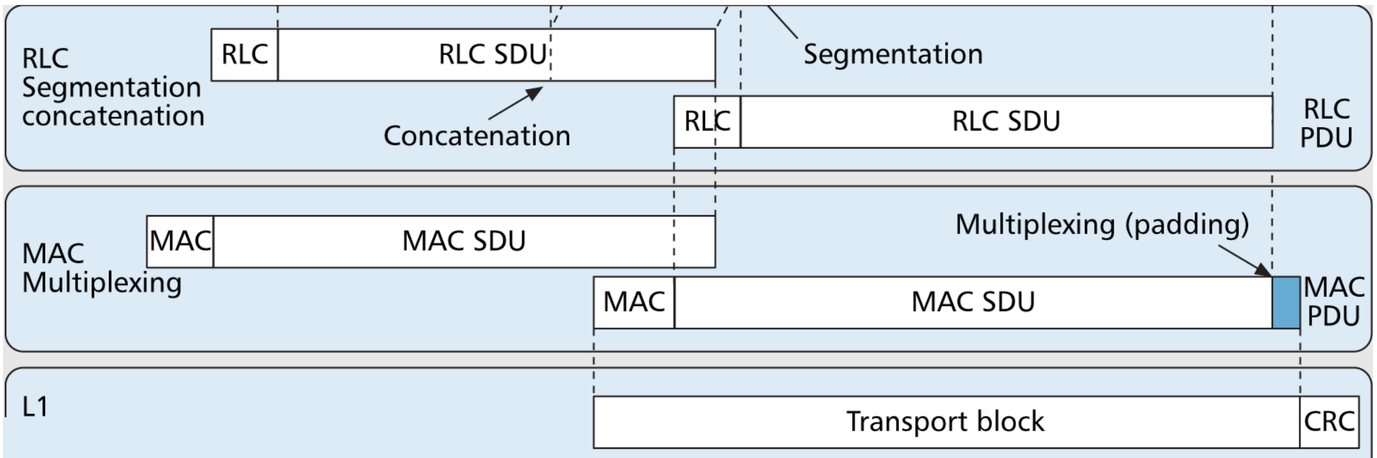
- Packets of different type (UTP, TCP,…) arrive at the PDCP (Packet Data Convergence Protocol) sublayer either from the S1 interface in eNB, or from the UE's protocol stack
- Packets headers are compressed forming PDCP SDUs (Service Data Unit) = H plus payload
- **PDCP PDU** consists of: a short PDCP header, compressed header and the original (UDP or TCP, …) payload
- There are two main types of the PDCP PDUs:
  - PDUs for user plane data
  - PDUs for the control plane data aka signalling

From the PDCP to the RLC sublayer



- PDUs (protocol Data Units) from the PDCP sublayer are **segmented** and **concatenated** to form RLC (Radio Link Control) PDU
- The size of the **RLC PDU** at each transmission opportunity is decided and notified by the MAC layer depending on the radio channel conditions and the available transmission resources
- The **RLC PDU** is formed from the segmented or concatenated RLC SDUs after adding an RLC header
- It is always byte aligned and has no padding.

From the RLC PDU to the Transport block



- MAC PDU is formed, in general, by multiplexing data from different **logical channels** to form data for the **transport channel**
- The MAC header is composed of MAC subheaders
- The MAC payload is composed of MAC control elements, MAC SDUs and padding
- The physical layer (L1) attaches a 24-bit CRC checksum to the MAC PDU and forms the physical layer Transport Block.