UNIVERSITÀ DELLA CALABRIA

Master Degree in Telecommunications Engineering

"Mobile Radio Networks" Class

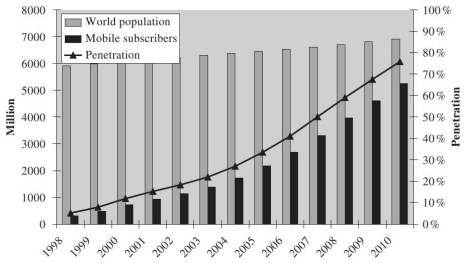
7 – LTE ⇨ LTE Advanced ⇨ LTE Advanced Pro

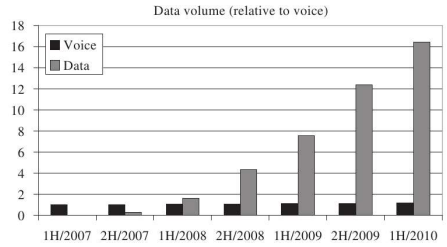
Antonio Iera
DIMES Department - University of Calabria
Arcavacata di Rende, ITALY
antonio.iera@dimes.unical.it

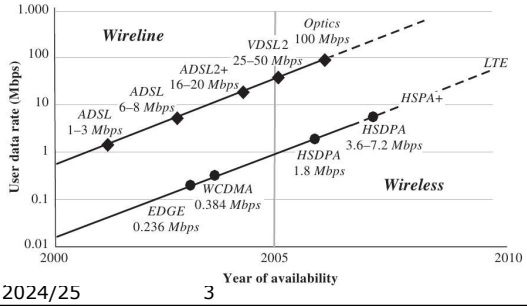
Mobile Radio Networks

- Long Term Evolution (LTE)

Towards LTE…

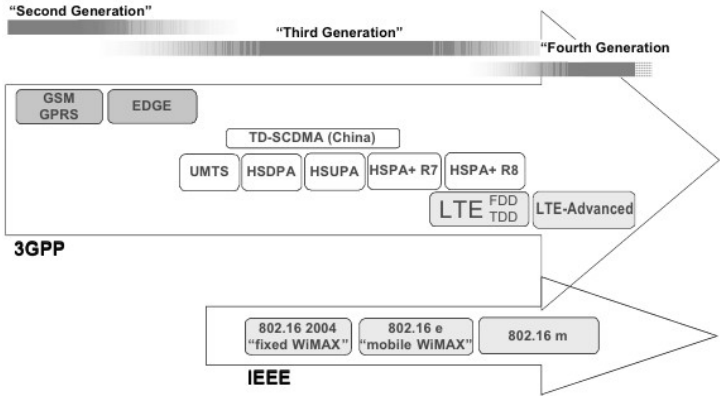






3

LTE –3GPP standardization



- LTE is standardized by the Third Generation Partnership Project (3GPP) in **Release 8** (2008)
- LTE represents the evolution of HSPA systems
- The LTE system is referred to as the **3.9G system**

4

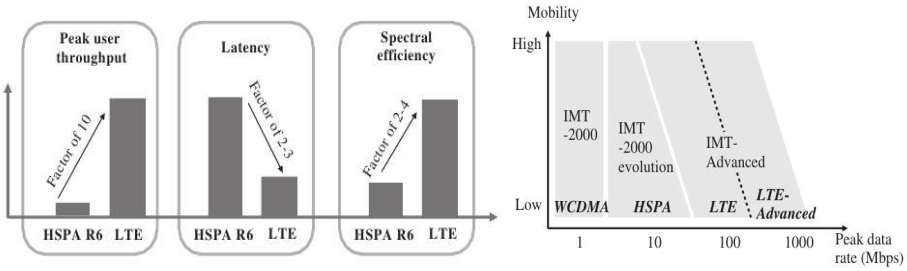
LTE – Key Features in Rel. 8 & Rel.9

LTE (up to 300 Mb/s)

- The 3GPP has launched in **Release 8** the standardization of the new LTE ultra-broadband technology called *EPS (Evolved Packet System),* divided into
  - Radio interface, E-UTRAN (Evolved UMTS Terrestrial Radio Access Network)
  - Core Network, EPC (Evolved Packet Core).
- Release 8 introduced basic EPS performance:
  - Radio interface, packet-only Core Network, functionality for voice service, both circuit-based CSFB (Circuit Switched Fall-Back) and packet-based VoLTE (Voice over LTE), the latter through the IMS (IP Multimedia Subsystem) architecture;
- **Release 9** has included some radio optimizations and features such as: the complete integration of the Femtocell concept (Home eNodeB) and evolved important features such as self organising networks (SON), evolved multimedia broadcast and multicast service (eMBMS), positioning support (LCS) and also added new spectrum bands (e.g., 800 MHz and 1500 MHz) for LTE operation.

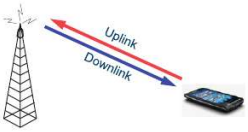
LTE Targets

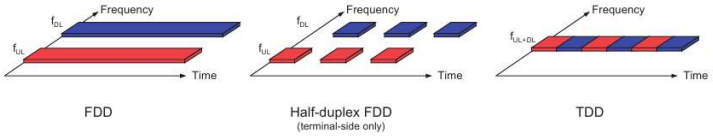
- Data rate increase (> 100 Mbps with 20 MHz channels)
- Better spectral efficiency (bit/s/Hz)
- Delay reduction (connection establishment and transmission latency)
- Flexibility in the allocation and use of the spectrum
- Simplification of the network architecture
- Cost reduction per bit
- Service guarantee up to speeds close to 350 km/h
- Inter Radio Access Network (RAT) handover
- Reasonable power consumption for terminals



LTE basics (1/6)

- **Different operating frequencies**
  - 400, 600, 800, 900 MHz (frequencies released thanks to DVB-T)
  - 1.8, 1.9, 2.6 GHz
  - LTE allocation in the spectrum currently occupied by other radio technologies (frequency refarming)
- **Different bandwidths**
  - 1.4, 3, 5, 10, 15, 20 MHz
- **Support of FDD, TDD, half-duplex**

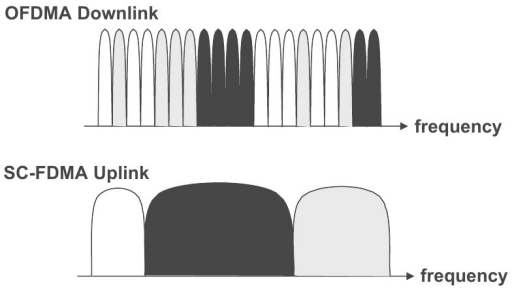




LTE basics (2/6)

Multi-carrier modulation

- Flexibility in bandwidth allocation
- Possibility to use different portions of spectrum without changing the parameters of the system
- Ability to exploit the frequency domain in scheduling procedures
- Greater robustness to time-dispersive radio channels
- Frequency-domain equalization
- Low complexity receivers



LTE basics (3/6)

Multiple Input Multiple Output (MIMO)

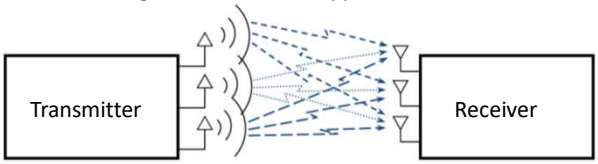
Multiple antenna systems are used, N connected to the eNodeB and M to the Terminal, which allow significant improvements in capacity and/or coverage.

Terminology for antennas
(example with *N=1* and *N=2* antennas at eNodeB and M=1 at the mobile terminal)

LTE basics (4/6)

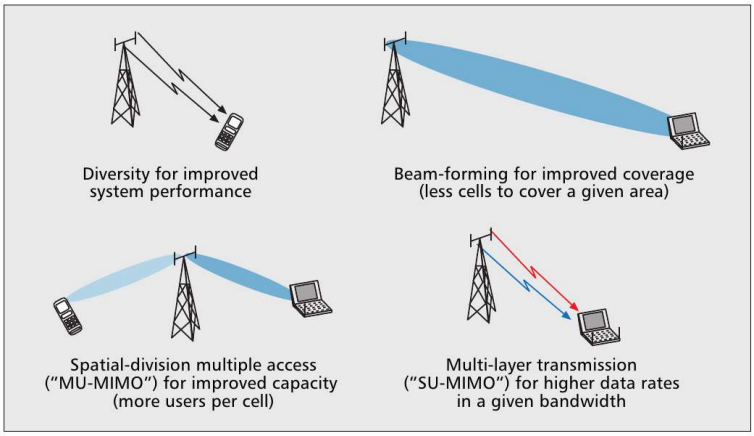
Multiple Input Multiple Output (MIMO)

- It allows parallel and simultaneous transmission of data at the same frequency with different antennas at the transmitter and receiver level.
- LTE provides different forms of MIMO: space multiplex, space diversity, beamforming or a combination thereof.
  - space multiplex allows a very high data transmission speed provided that the radio channel is of good quality
  - space diversity allows to improve the quality of the channels in case of strong and rapid attenuation of the signal (fading). Depending on the scheduling algorithm, the channel resources (PRB) are attributed to users who have the best momentary conditions of the transmission channel (Multi User Space Diversity).
  - beamforming allows to propose simultaneously the same resources (SDMA) to different users. Strong interference signals can also be suppressed.



LTE basics (5/6)

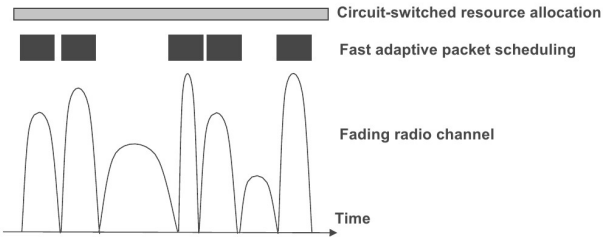
Multiple Input Multiple Output (MIMO)



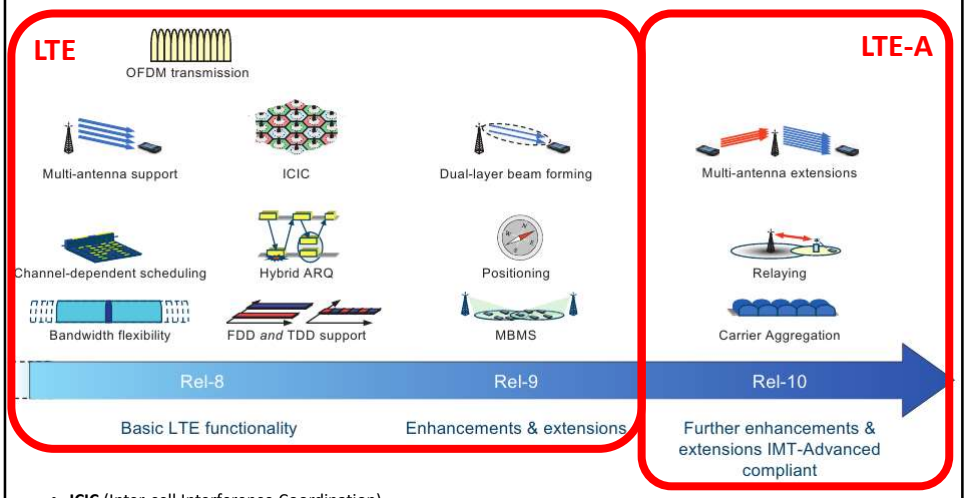
LTE basics (6/6)

Packet-Switched Radio Interface

- Fully packet-oriented network
- Reduced latency
- Voice over LTE (VoLTE)
- High-quality multimedia service
- Adaptive scheduling in the fequential and temporal domain



Rel. 8 – Rel. 10



- **ICIC** (Inter-cell Interference Coordination)
- **MBMS** (Multimedia Broadcast Multicast Services)

Mobile Radio Networks

❑ Long Term Evolution (LTE)

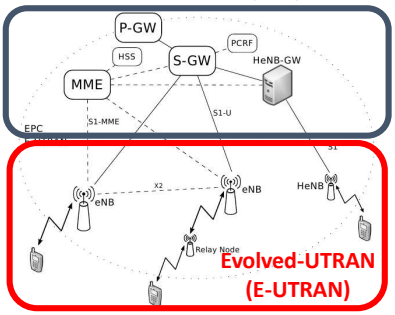
Network Architecture

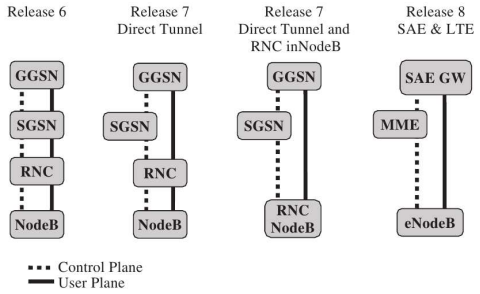
LTE & SAE

The work carried out by 3GPP has focused on two projects:

- Long Term Evolution (LTE) which defines the access network
- System Architecture Evolution (SAE) which defines the core network

Evolved Packet Core (EPC)





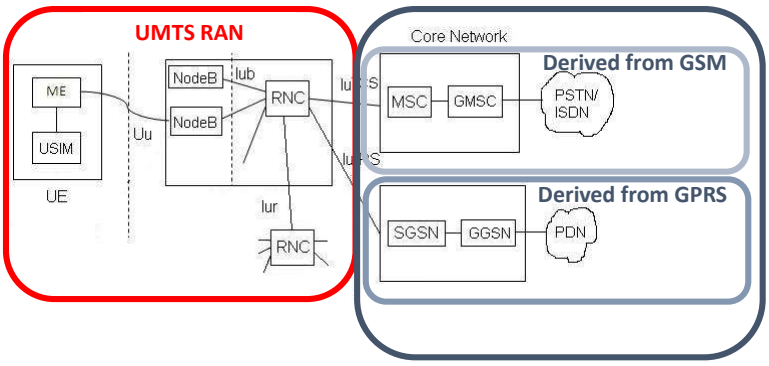
HSS: stores information to authenticate the user
PCRF: stores profiles for QoS management

All types of traffic (control and user plane) travel over IP

Previous core network

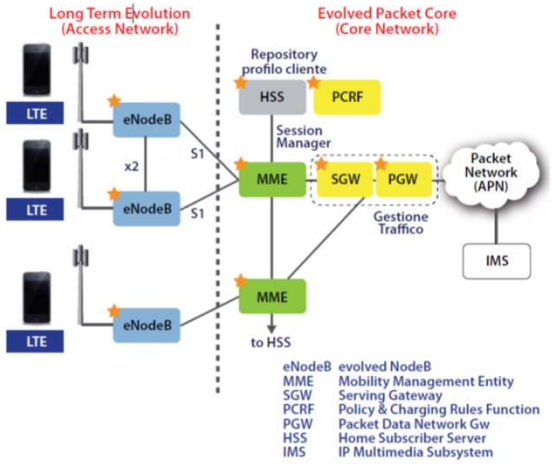
The work carried out by 3GPP has focused on two projects:

- Long Term Evolution (LTE) which defines the access network
- System Architecture Evolution (SAE) which defines the core network



Radio Network Controller (RNC)

LTE & SAE

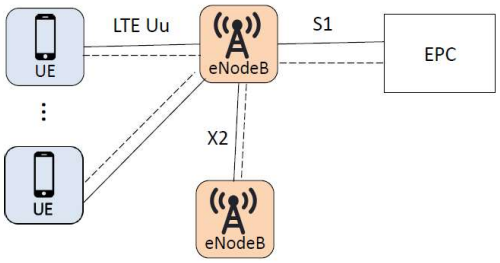


TIM

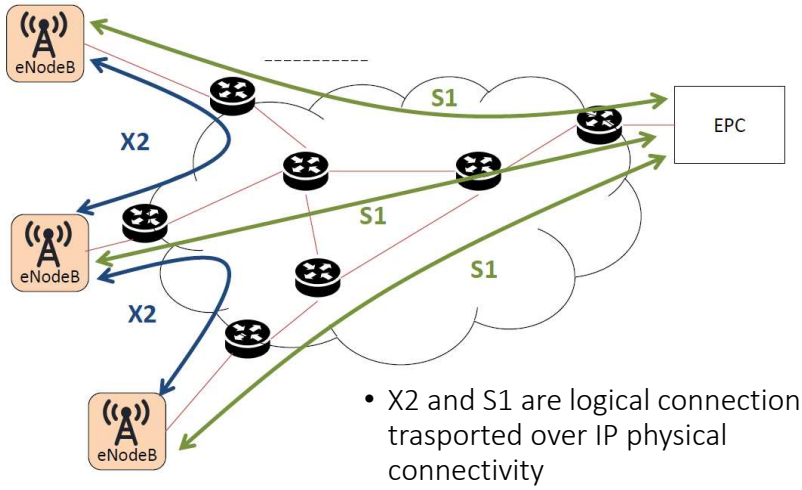
The elimination of the eNB control node (RNC), by shifting the functions both to the eNB and to the Core Network nodes, allows a more streamlined architecture (Flat) to achieve the goal of lower latency and greater throughput.

LTE - E-UTRAN

- eNBs are connected together through the X2 interface for managing handovers and intercell coordination functions
- Only neighboring eNodeBs are connected and X2 interface is self configured



LTE - E-UTRAN: IP transport



- X2 and S1 are logical connections trasported over IP physical connectivity

User Equipment (UE)

- Handheld, smartphone, USB-card, sensors, etc.
- It includes
  - UICC (Universal Integrated Circuit Card) with the USIM (Universal Subscriber Identity Module)
  - TE (Terminal Equipment)
- It can include also a VoIP client for LTE voice calls (VoLTE)
- It can have multiple antennas for MIMO support
- Most of UE will be multi standard: GSM, HSPA e LTE (FDD o TDD)

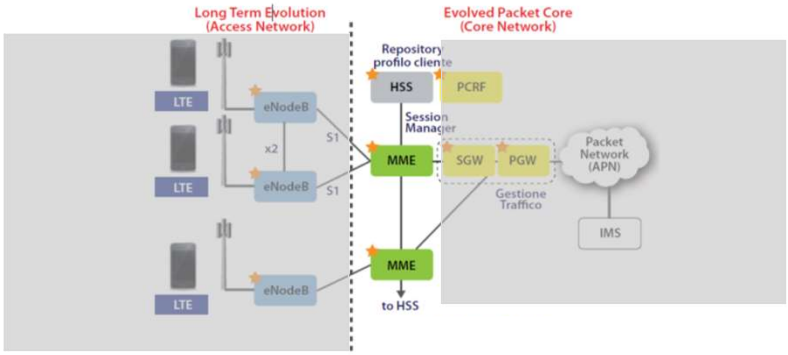
eNB – Evolved Node B

- It's the base station of eUTRAN, which manages one or more cells
- With respect to GSM and UMTS it also performs additional functions (that were performed by BSC and RNC) like for instance handover
- All radio protocols are terminated on the eNB
- for IP connectivity the eNB acts as relay towards the EPC (layer 2 bridge)
- The eNB manages radio resources and mobility
- The eNB can be connected to a set of MME/S-GWs, even if each UE is connected to only one of these

eNB – Evolved Node B

- Main functions
  - Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Scheduling in UL and DL)
  - IP header compression and data flow encryption
  - MME selection in case of request from UE
  - Routing of User Plane data towards the Serving Gateway
  - Scheduling and transmission of
    - Paging messages (originated by MME)
    - Broadcast (originated by MME or O&M)
  - Measurements for mobility and scheduling

LTE & SAE: MME (Mobility Management Entity)



TIM

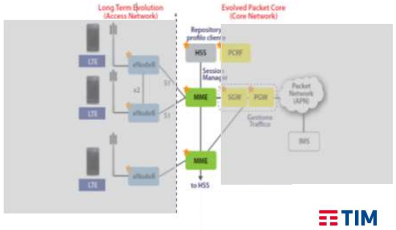
MME (Mobility Management Entity) is the main node of the Core Network SAE/LTE:

- It includes most of the functions that in 2G/3G networks were implemented in different nodes
- It is involved in the Control Plane only
- It establishes a direct connection with the UE
- It is connected simultaneously with several UEs, eNBs, MMEs (even of different operators), SGWs, and HSSs

LTE & SAE: MME (Mobility Management Entity)

MME (Mobility Management Entity)

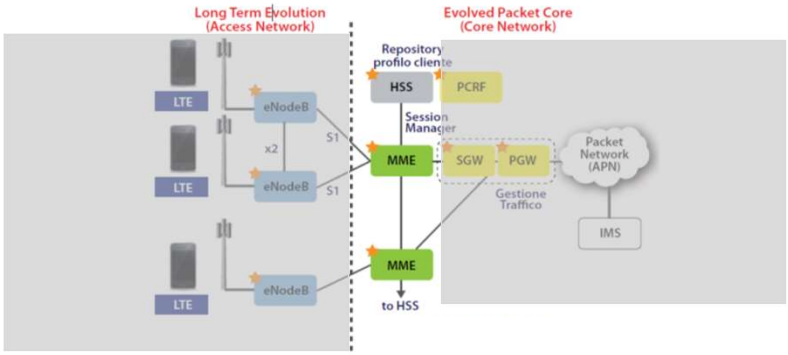
- Authentication and Security
  - Together with the HSS it manages authentication and encryption of channels for Control Plane and User Plane
- Mobility Management
  - It asks eNB and S-GW to allocate resources for UE when they register to the network
  - It stores the Tracking Area (or the eNB if in active mode) that UE communicates periodically
  - It is involved in handover procedures together with eNB, S-GW and other MME



TIM

- User Profile Management and Service Connectivity
  - It provides the basic connectivity for the initial exchange of messages between UE and network (default bearer)
  - It selects the Packet Data Network to be assigned to each UE
  - When requested by the network (S-GW) or UE, it establishes a new bearer (dedicated)
  - The MME verifies the profile and services for the UE before allocating the bearer

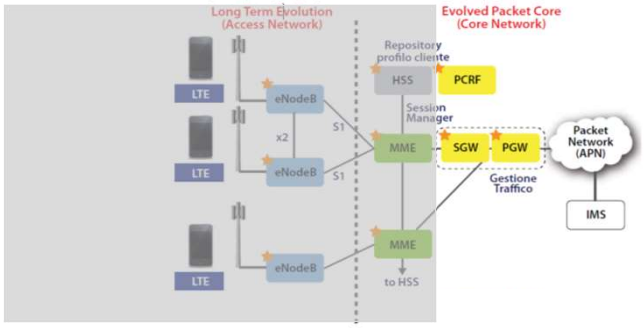
LTE & SAE: HSS (Home Subscriber Server)



HSS (Home Subscriber Server) contains user profile and position information and can optionally cooperate with the HLR (e.g. acquisition of user authentication keys).

- It's the home register of the 4G architecture and it has the same basic functions of the HLR in 2G/3G architectures
- HSS implements the specific signaling protocols of the new 4G architecture
- As most operators run multi-technology networks, HLR and HSS functionalities and interfaces are combined together so that subscribers can access any technology

LTE & SAE: SGW (Serving Gateway)

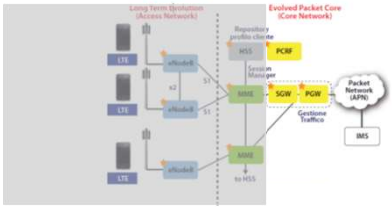


SGW (Serving Gateway) is a transport node with User Plane functionality similar to the transport component of the SGSN:

- interacts with the *PGW (PDN Gateway)* for the transport of user data by managing user mobility between 3GPP accesses (e.g. E-UTRAN and 2G/3G)
- it can change according to the destination eNode B in the handover procedure.

LTE & SAE: SGW (Serving Gateway)

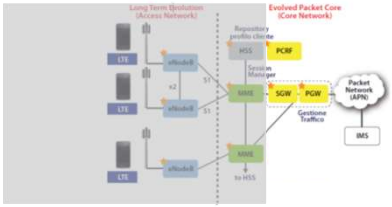
SGW (Serving Gateway)



- The S-GW is in charge of managing the tunnel of UP protocols and switching the tunnel in case of mobility
- The S-WG manages its own resources based on requests from MME, P-GW and PCRF
- It's the "anchor" node for terminals moving between different eNodeB. When requested by the MME, the S-GW reroutes data flows between the eNBs involved in a handover
- In case of inter-S-GW handover, the MME deletes the IP tunnel from old S-GW and establishes a tunnel with the new S-GW
- When the P-GW sends packets to a UE in IDLE, the S-GW buffers packets and requests to MME to perform the paging procedure
- The S-GW stores traffic statistics and it is involved in the interworking with other 3GPP systems, like GSM e UMTS

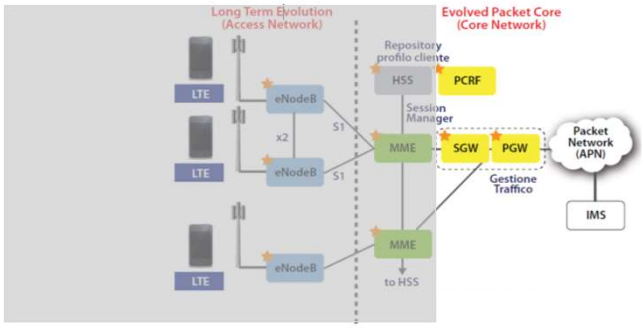
LTE & SAE: SGW (Serving Gateway)

FUNCTIONS of Serving Gateway



- Mobility anchor point for the inter-eNB handover
- Mobility anchoring for inter-3GPP mobility
- Data buffering in downlink for idle UE
- Service instantiation for requests from the network
- Routing and packet forwarding
- Packet tagging at transport layer in uplink and downlink
- Charging in UL and DL UE, PDN, and QCI

LTE & SAE: PGW (PDN Gateway)



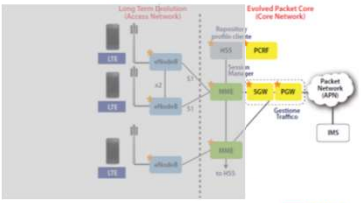
PGW (PDN Gateway) is a transport node with functionality similar to GGSN:

- assigned by the network depending on the service requested and, even in the presence of mobility, it remains the same for the interconnection to the PDN (Packet Data Network).
- chosen according to the APN, stored in the terminal, identifying the service requested by the user.

LTE & SAE: PGW (PDN Gateway)

PGW (PDN Gateway)

- The PGW assigns an IP address to the user terminal during the activation of the PDP Context data following the user's request to register on the network.
  - in LTE service fruition is in packet-only modality → IP address assignement is of the always-ON type and, thus, the IP address is assigned as long as the terminal is not turned off.

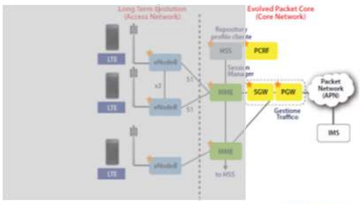


- The P-GW manages the IP addresses assigned to Ues (IPv4/IPv6, DHCP)
- Together with the PCRF, it controls QoS and charging based on traffic flow
- Through the PCEF (a component of the P-GW), it filters IP traffic and calculate statistical information
- The P-GW allows the interworking with non-3GPP packet technologies like WiMAX and WLAN

LTE & SAE: PGW (PDN Gateway)

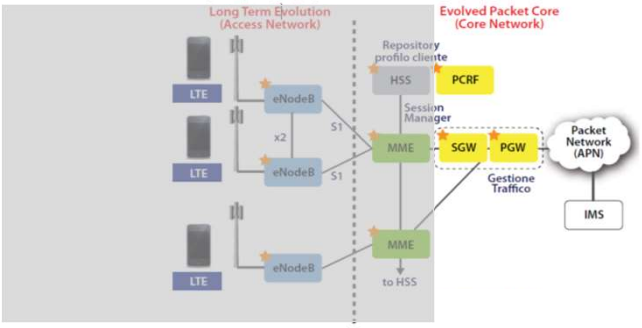
FUNCTIONS of PDN Gateway

- Mapping of IP flows and GTP tunnels
- Packet filtering per single UE
- Traffic interception
- IP address allocation for UE
- Charging based on active services in UL and DL
- Data rate control in Downlink



TIM

LTE & SAE

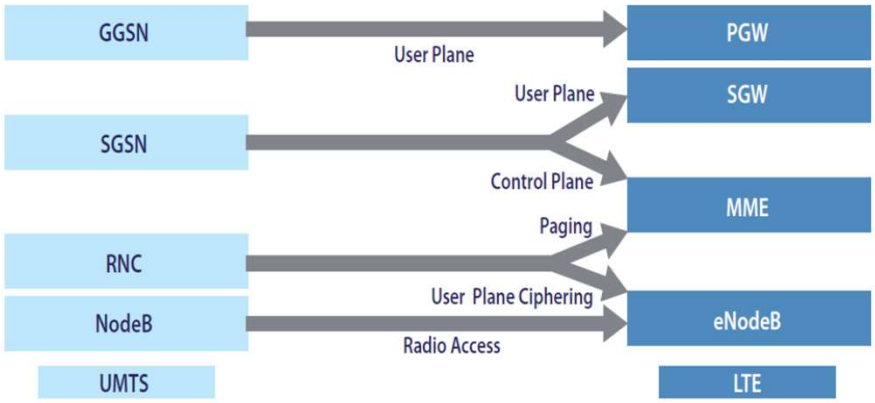


PCRF (Policy and Charging Rules Function) is responsible for the policies (of QoS, gating , charging) on a user and service basis.

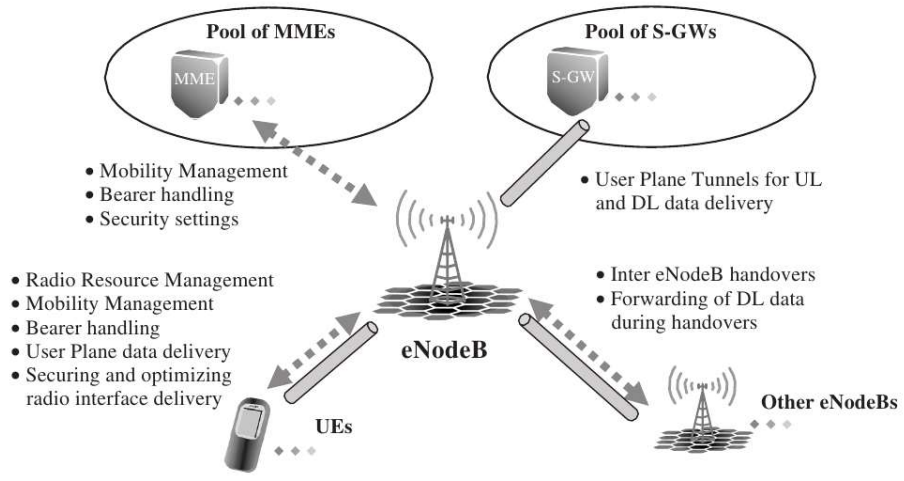
- To implement these policies, it works with the PGW and makes use of the PCEF (Policy and Charging Enforcement Function) function in the PGW.

TIM

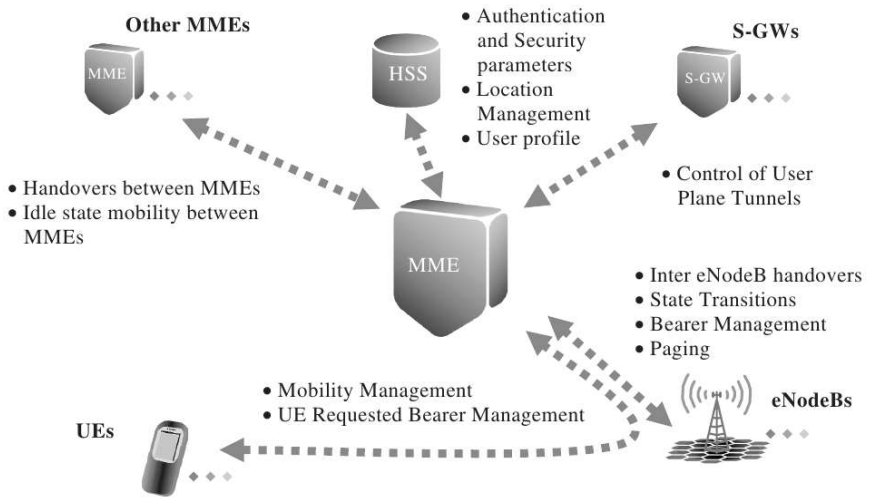
Functionality migration from UMTS to LTE



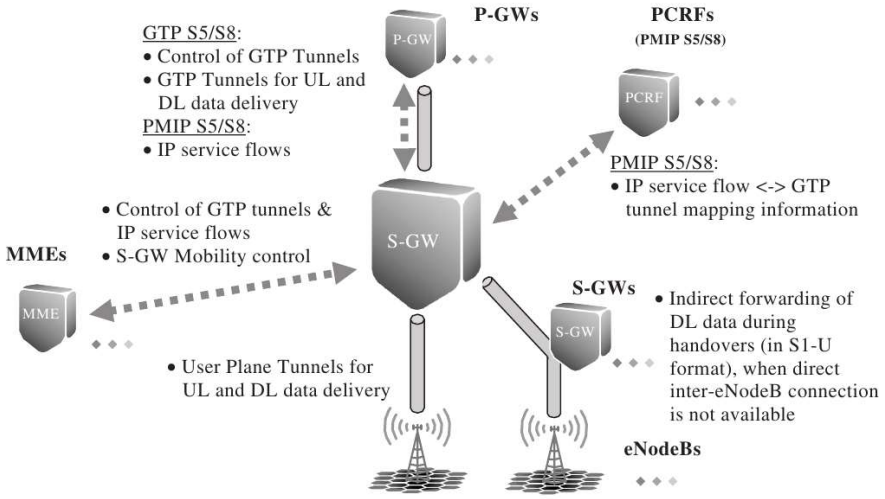
eNodeB



Mobility Management Entity



Serving Gateway



Radio bearers

Definition

- Logical channels established between UE and eNB. IP packets are mapped to a bearer according to QoS requirements.

Default bearer

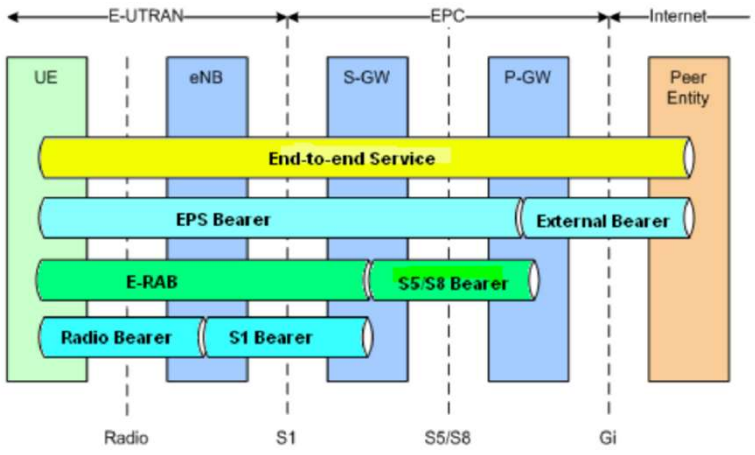
- Created when a UE joins the network.
- Used for basic connectivity and exchange of control messages.
- It remains established during the entire lifetime of the connection.

Dedicated bearers

- Set up every time a new specific service is issued.
- Depend on QoS requirements.
- Classified as Guaranteed bit-rate (GBR) or non-guaranteed bit rate (non-GBR) bearers.
- A set of QoS parameters is associated to each bearer.

@ G. Piro

Radio bearers differentiation/classification



@ G. Piro

Radio bearer- QoS Class Identifiers

- A **radio bearer** defines the parameters that characterize a data flow (either in the user or in the data plane)
- The RRM module translates QoS requirements into: scheduling parameters, admission policies, queue management thresholds, link layer protocol configurations, and so on.

Guaranteed Bit Rate

NON-GBR

QCI	Resource type	Priority	Packet delay budget (ms)	Packet error loss rate	Example services
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	5	300	10^{-6}	Non-conversational video (buffered streaming)
4	GBR	3	50	10^{-3}	Real time gaming
5	Non-GBR	1	100	10^{-6}	IMS signalling
6	Non-GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7	Non-GBR	6	300	10^{-6}	Video (buffered streaming)
8	Non-GBR	8	300	10^{-6}	TCP-based (e.g. WWW, e-mail) chat, FTP, p2p file sharing, progressive video, etc.
9	Non-GBR	9	300	10^{-6}	