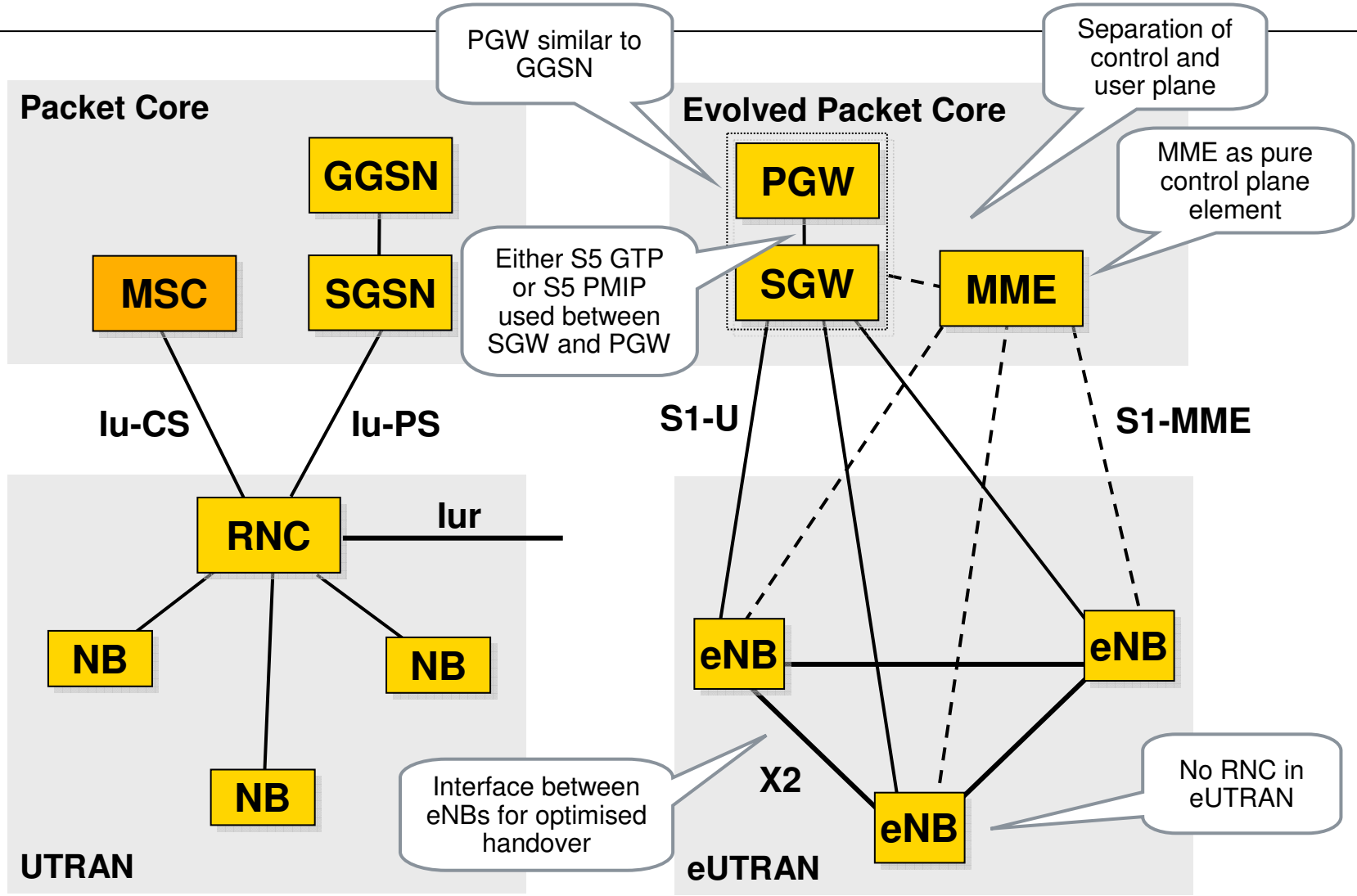
LTE/EPC
Evolved Packet Core
Workshop

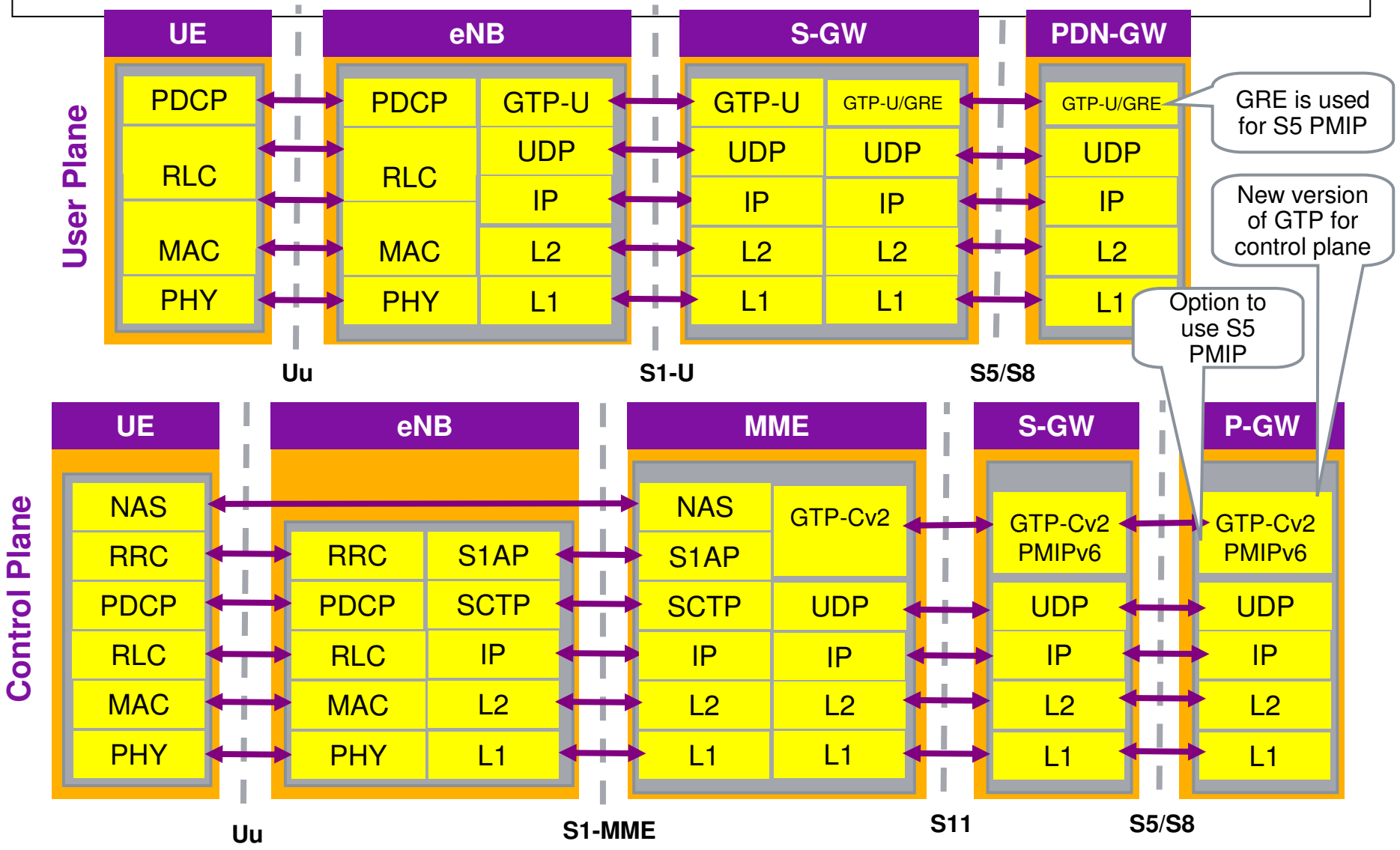
Comparison of 3G and LTE Architectures



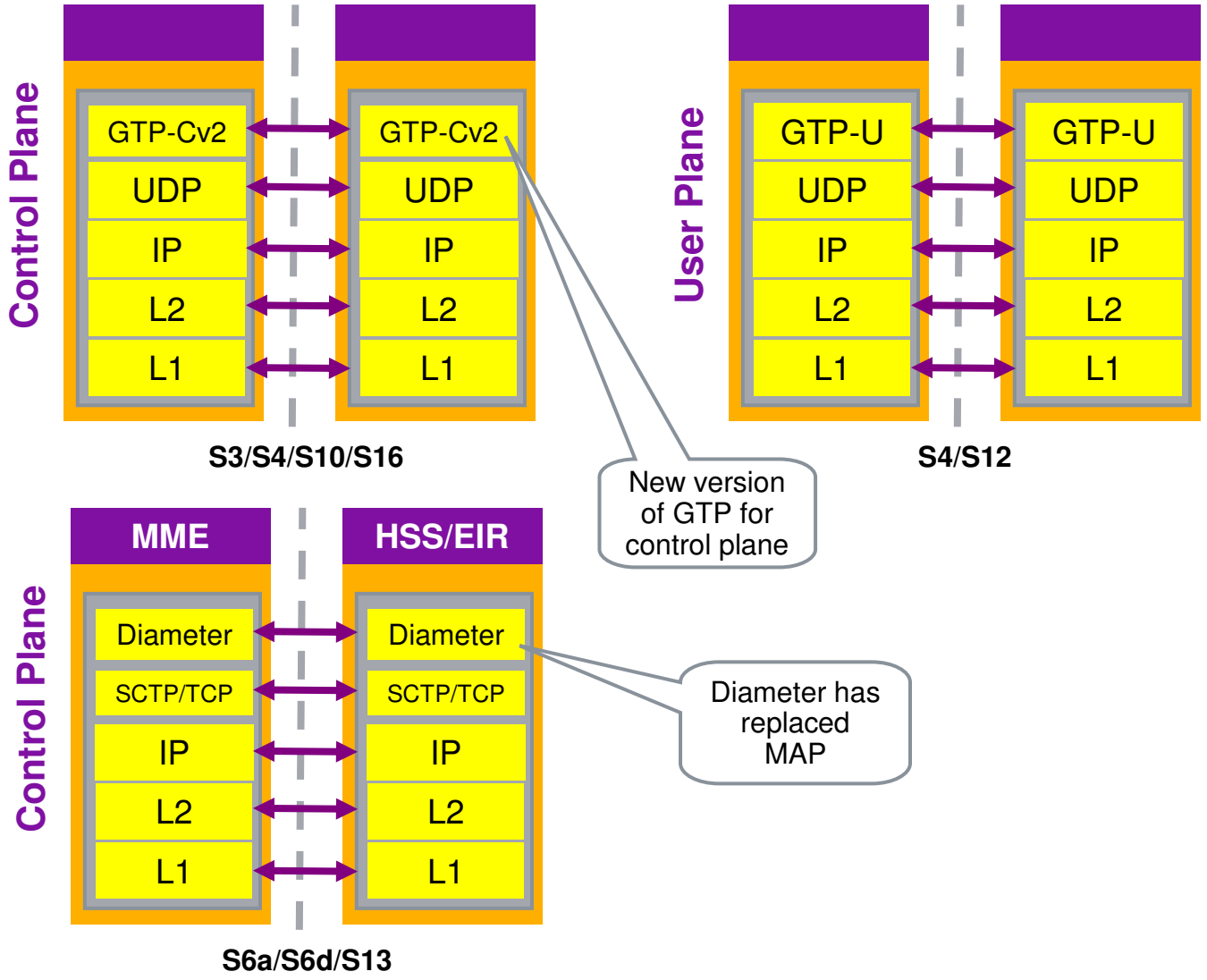
Terminology in LTE and in 3G
Connection and Mobility Management

3G	LTE
Connection management	
GPRS attached	EMM registered
PDP context	EPS bearer
Radio access bearer	Radio bearer + S1 bearer
Mobility management	
Location area	Not relevant (no CS core)
Routing area	Tracking area
Handovers (DCH) when RRC connected	Handovers when RRC connected
RNC hides mobility from core network	Core network sees every handover

Protocols for Control and User Plane (1/2)



Protocols for Control and User Plane (2/2)

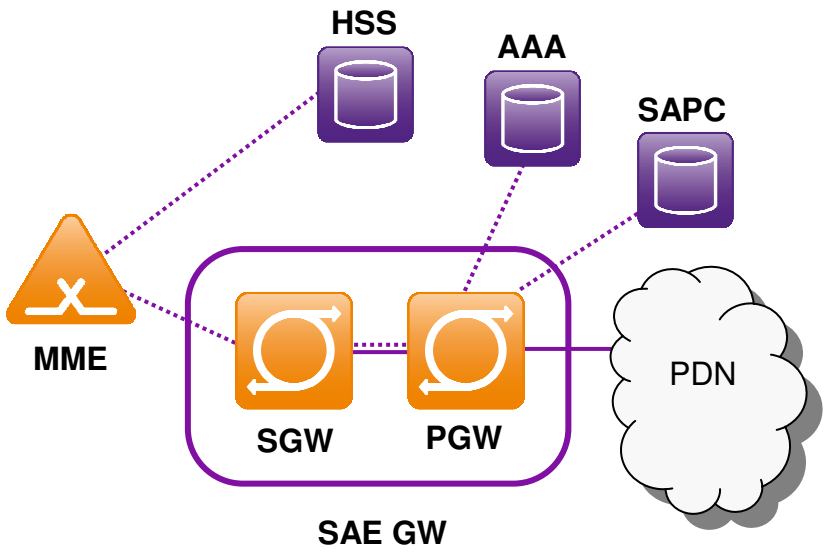


EPC main functions

Mobility Management Entity (MME)
- NAS signaling & security
- Authentication & authorization
- Idle mode Mobility Management
- Inter CN node signaling for mobility
- P-GW & S-GW selection
- Bearer management
- Lawful Interception for signaling
- Roaming (S6a towards home HSS)

Serving Gateway (SGW)
- Local Mobility gateway for inter-eNB handover
- Local Mobility gateway for 3GPP accesses
- ECM-IDLE mode handling (DL packet buffering)
- Lawful Interception for U-plane in roaming
- Packet routing & forwarding
- Bearer binding and packet classification (for PMIP)
- Accounting & charging support

Packet Data Network Gateway (PGW)
- Interface to PDN
- UE IP address allocation
- Policy Enforcement
- Per-user based packet filtering
- Bearer binding and packet classification
- Charging Support
- Lawful Interception for U-plane
- Mobility anchor for 3GPP and non-3GPP interworking



In addition:

EPC provides CS interworking with CS fallback or Single Radio Voice Call Continuity (SRVCC)

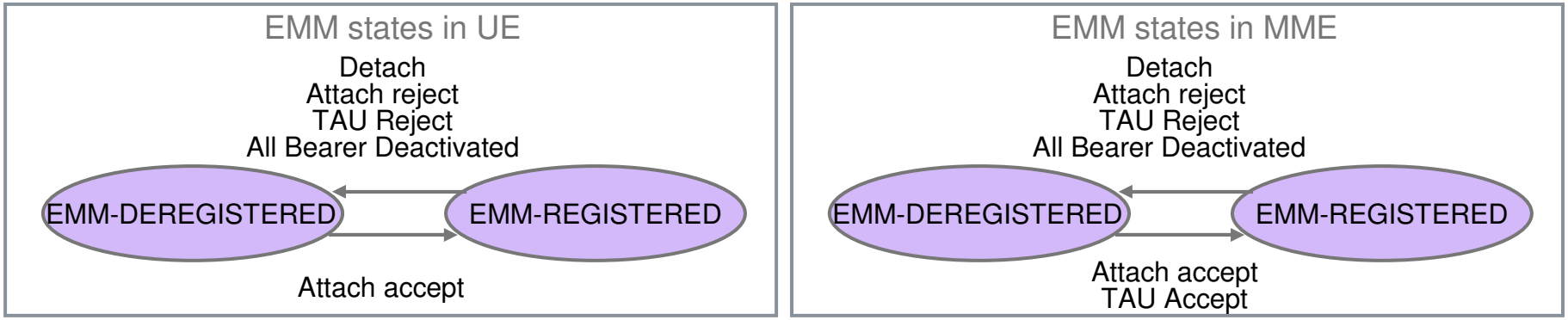
Mobility Management States

General

- The EPS Mobility Management (EMM) states describe the Mobility Management.
- The EPS Connection Management (ECM) states describe the signalling connectivity between the UE and the EPC.

Definition of main EPS Mobility Management states

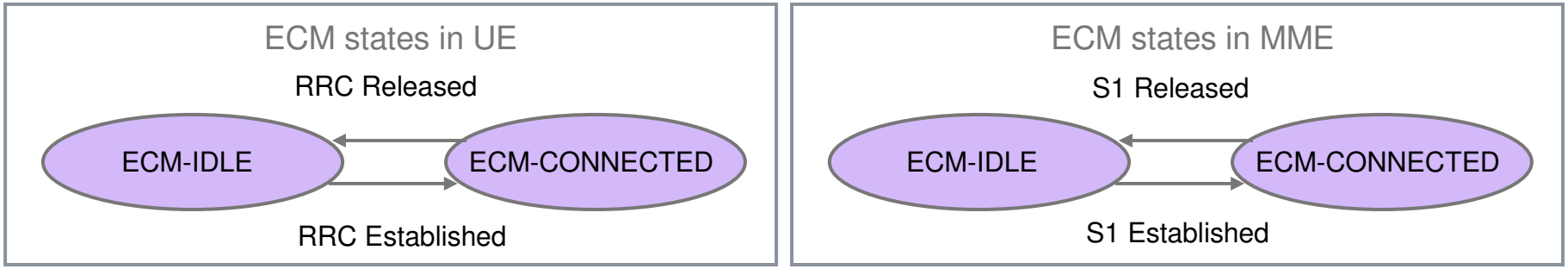
- EMM-DEREGISTERED
  - The UE is not reachable by a MME.
  - UE context can still be stored in the UE and MME
- EMM-REGISTERED
  - UE enters to EMM-Registered with Attach or Tracking Area Update procedure.
  - The UE location is known an accuracy of the tracking area list.
  - UE has at least one active PDN connection;
  - After Detach procedure the state is changed to EMM-DEREGISTERED



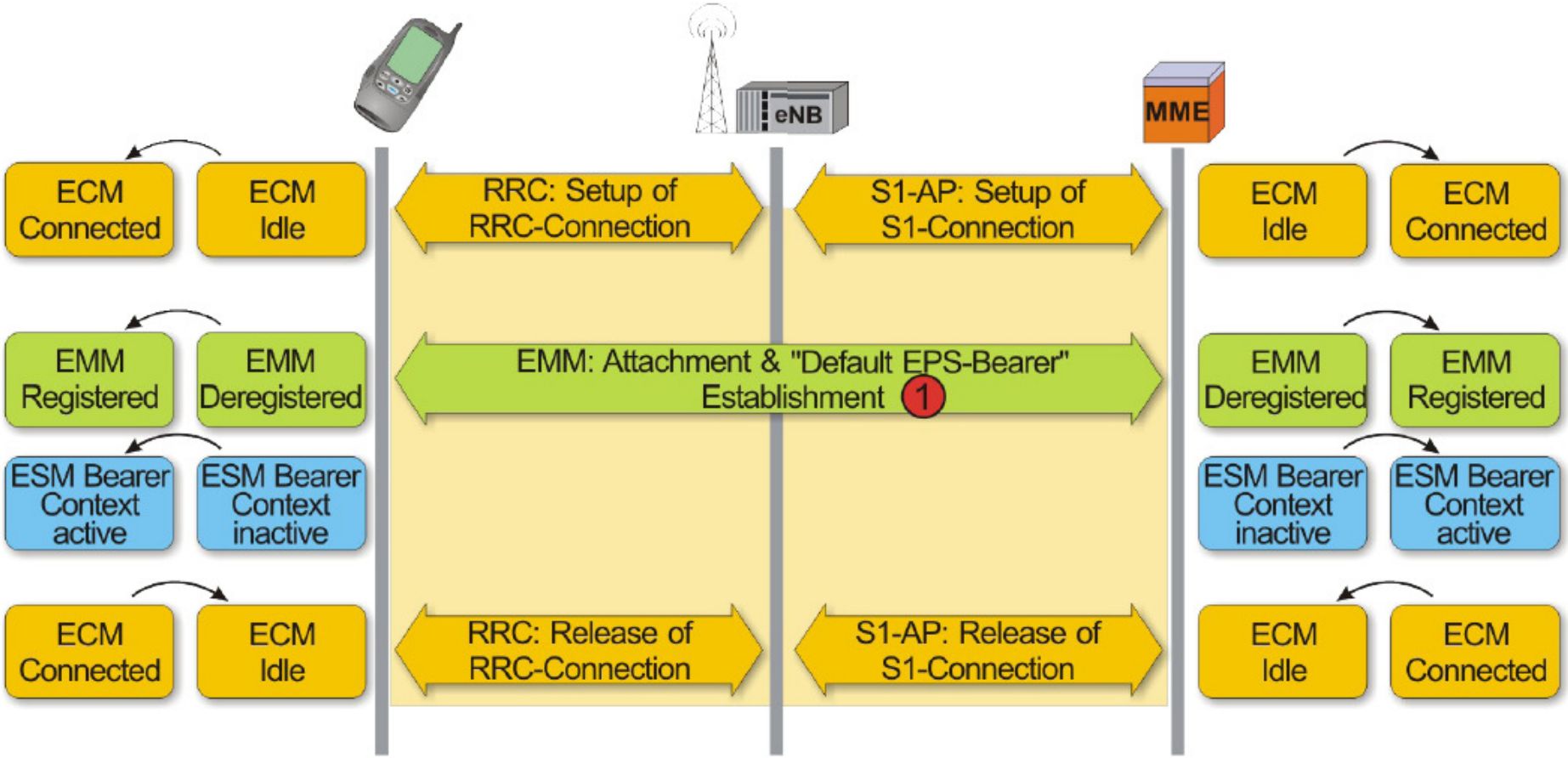
Mobility Management States

Definition of EPS Connection Management states

- ECM-IDLE
  - UE is in ECM-IDLE state when no NAS signalling connection between UE and network exists.
  - In the EMM-REGISTERED and ECM-IDLE state, the UE shall perform:
    - Tracking Area Update
    - Periodic Tracking Area Update
    - Service Request
    - Answer to paging from MME with Service Request
  - UE and MME enter the ECM-CONNECTED state when signalling connection is established.
- ECM-CONNECTED
  - UE location is known in the MME with an accuracy of a serving eNodeB.
  - For a UE in the ECM-CONNECTED state, there exists a signalling connection between the UE and the MME.
  - The S1 release procedure changes the state at both UE and MME from ECM-CONNECTED to ECM-IDLE.



States and transitions



EMM & ECM States Summary

EMM_Deregistered

ECM_Idle

Network Context:
• no context exists

Allocated IDs:
• IMSI

UE Position:
• unknown to network

Mobility:
• PLMN/cell selection

UE Radio Activity:
• none

EMM_Registered

ECM_Connected

Network Context:
• all info for ongoing transmission/reception

Allocated IDs:
• IMSI, S-TMSI per TAI
• 1 or several IP addresses
• C-RNTI

UE Position:
• known on cell level

Mobility:
• NW controlled handover

UE Radio Activity:
• DL w/o DRX
• UL w/o DTX

EMM_Registered

ECM_Idle

Network Context:
• security keys
• enable fast transition to ECM_CONNECTED

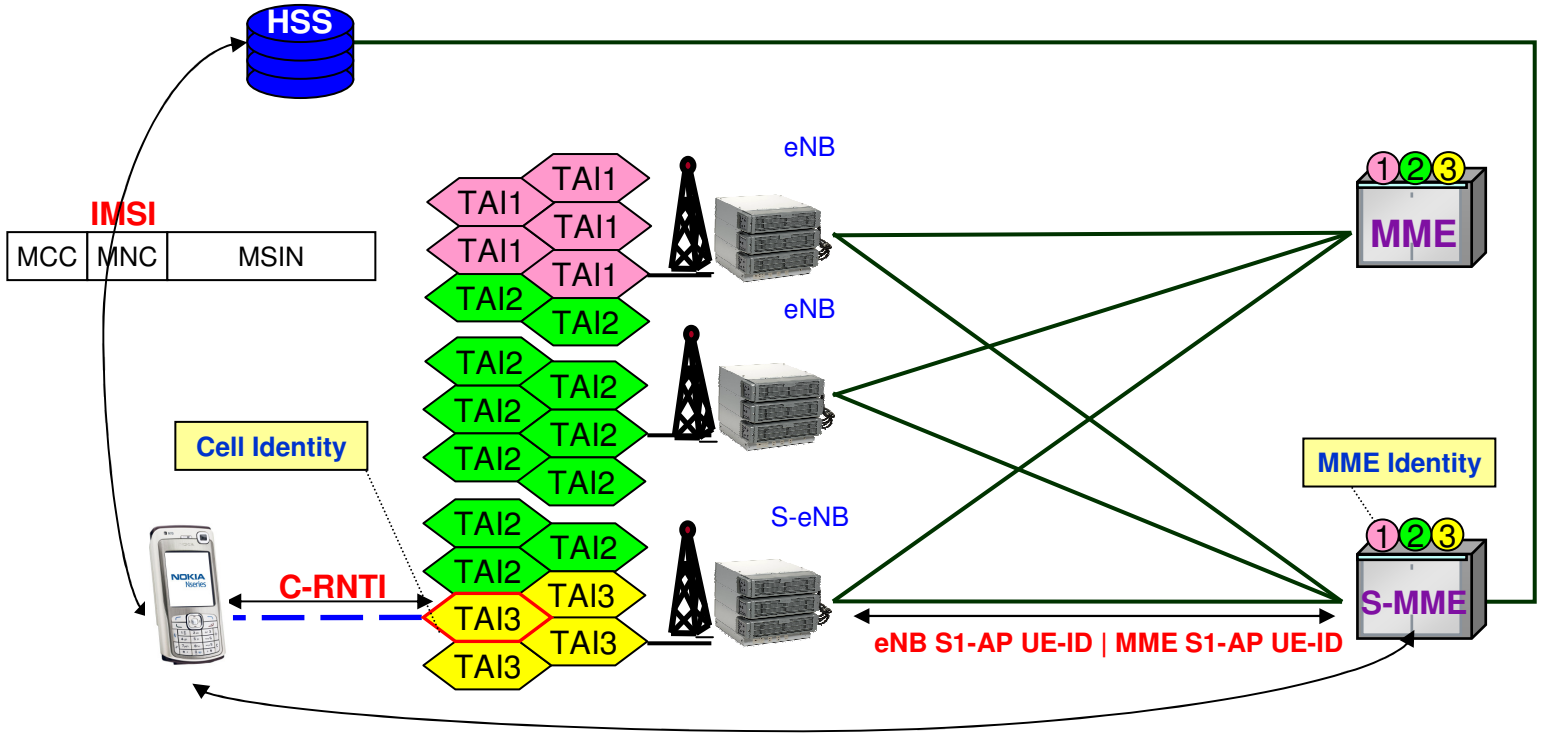
Allocated IDs:
• IMSI, S-TMSI per TAI
• 1or several IP addresses

UE Position:
• known on TA level (TA list)

Mobility:
• cell reselection

UE Radio Activity:
• DL DRX for paging
• no UL

UE Identifications



IMSI	International Mobile Subscriber Identity
S-TMSI	S-Temporary Mobile Subscriber Identity
C-RNTI	Cell Radio Network Temporary Identity
S-MME	Serving MME
S-eNB	Serving E-Node B
TAI	Tracking Area Identity (MCC+MNC+TAC)

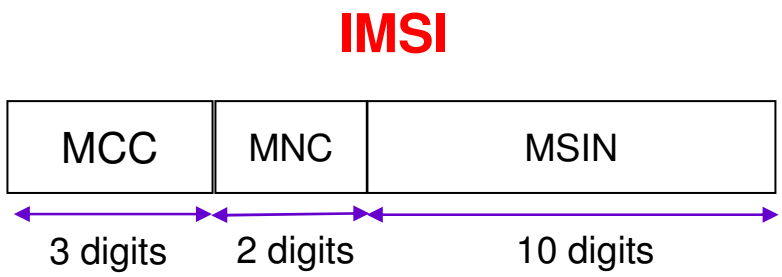
S-TMSI

	MME-ID or MME color code	

UE Identifications: IMSI

IMSI:

- International Mobile Subscriber Identity.
- Used in SAE to uniquely identify a subscriber world-wide.
- Its structure is kept in form of MCC+MNC+MSIN:
  - MCC: mobile country code
  - MNC: mobile network code
  - MSIN: mobile subscriber identification number
- A subscriber can use the same IMSI for 2G, 3G and SAE access.
- MME uses the IMSI to locate the HSS holding the subscribers permanent registration data for tracking area updates and attaches.

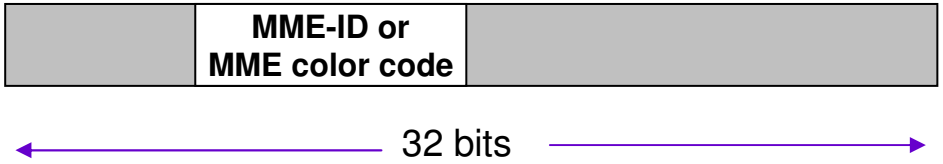


UE Identification: S-TMSI

S-TMSI:

- SAE Temporary Mobile Subscriber Identity
- It is dynamically allocated by the serving MME (S-MME).
- Its main purpose is to avoid usage of IMSI on air.
- Internally the allocating MME can translate S-TMSI into IMSI and vice versa.
- Whether the S-TMSI is unique per MME or per TA is not clear yet.
- In case the S1flex interface option is used, then the eNB must select the right MME for a UE. This is done by using some bits of the S-TMSI to identify the serving MME of the UE. This identifier might be a unique MME ID or a form of MME color code. Under investigation.

S-TMSI



UE Identifications: C-RNTI

C-RNTI:

- Cell Radio Network Temporary Identity
- C-RNTI is allocated by the eNB serving a UE when it is in active mode (RRC_CONNECTED)
- This is a temporary identity for the user only valid within the serving cell of the UE.
- It is exclusively used for radio management procedures.
- X-RNTI identifications under investigation.

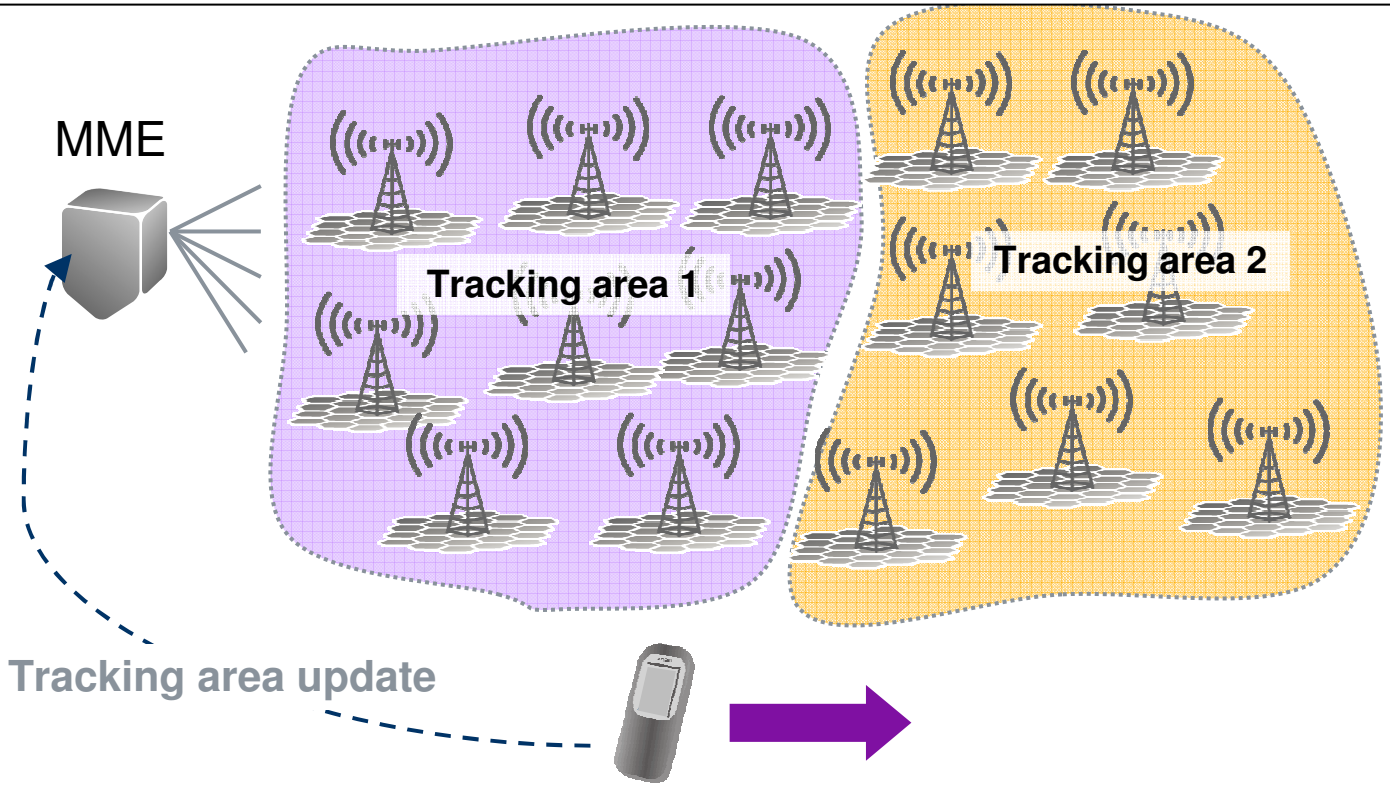
UE Identifications:S1-AP UE ID

S1-AP UE ID:

- S1 Application Protocol User Equipment Identity.
- Two additional temporary identifiers allocated by eNB and MME:
  - eNB S1-AP UE ID
  - MME S1-AP IE ID
- Their purpose is to allow efficient implementation of S1 control signaling (S1AP=S1 Application Protocol)
- They shall allow easy distribution of S1 signaling messages inside MME and eNB.
- NOTE: This concept is similar to SCCP local references known from Iu or A interface in 3G/2G.

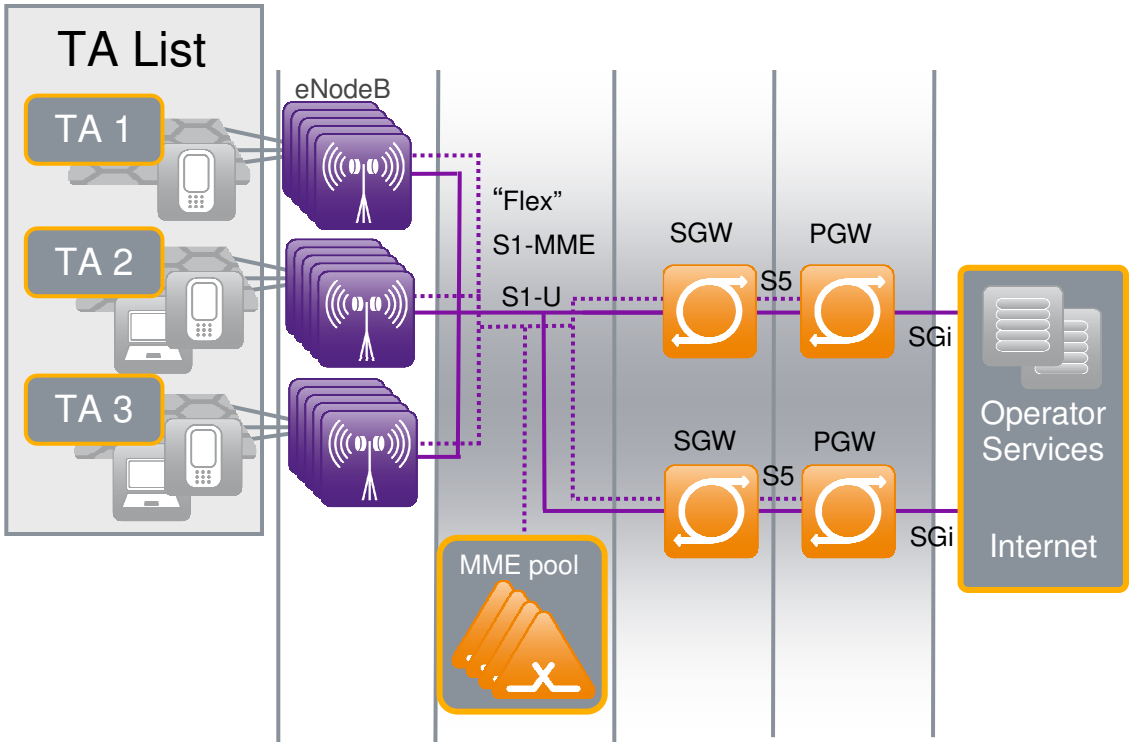
LTE Tracking Area

- Tracking area (TA) is similar to Location/routing area in 2G/3G
- Tracking Area Identity = **MCC** (Mobile Country Code), **MNC** (Mobile Network Code) and **TAC** (Tracking Area Code)
- When UE is in Idle, MME knows UE location with Tracking Area accuracy



Tracking Area List

- TA can cover one or more eNodeBs
- TA list can cover one or more TAs
- TA list benefits over adding eNodeBs to single TA is that TA list can be created based on subscriber needs.
  - E.g. History of movement

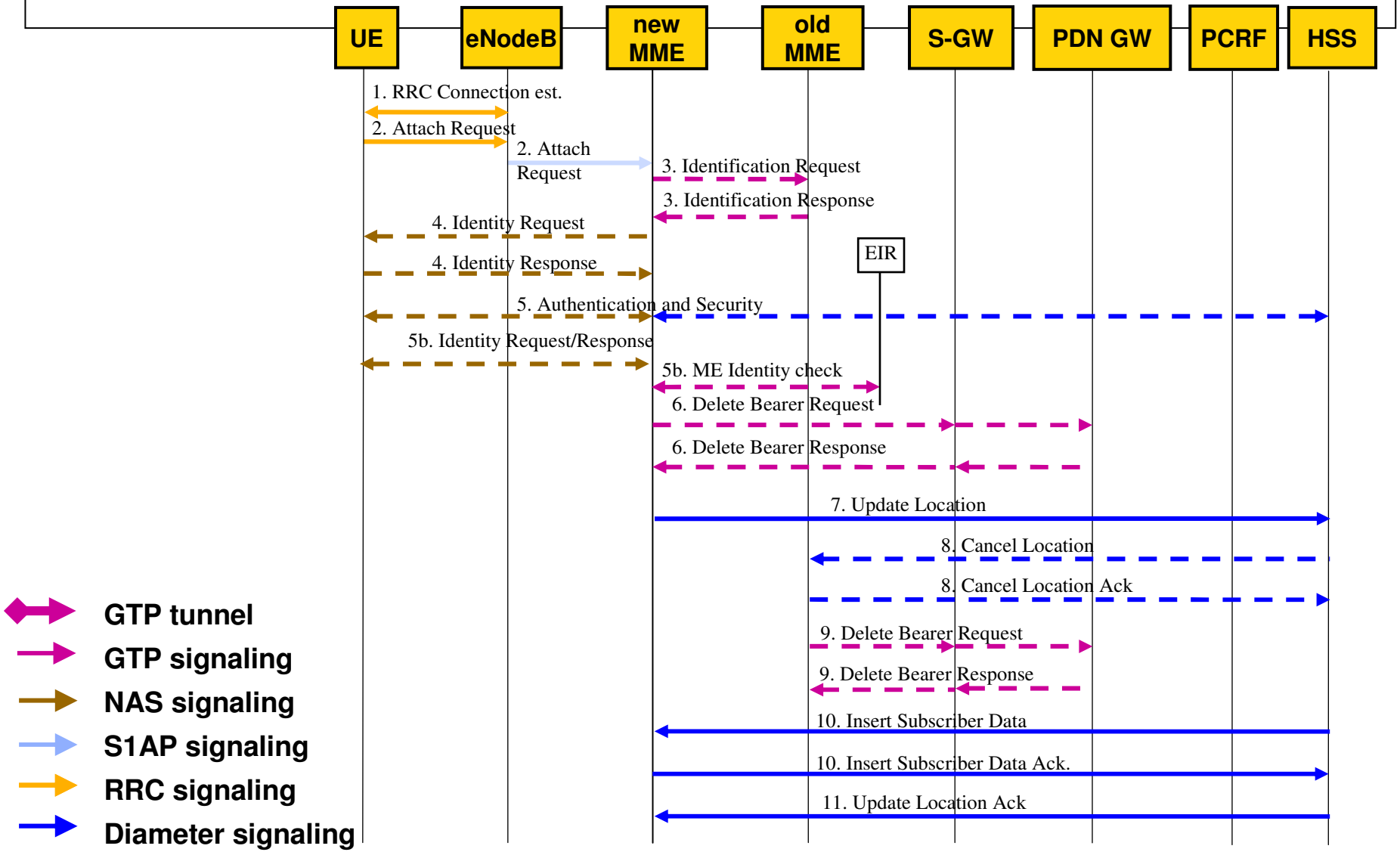


- TA list is send to UE
- TAU is needed when subscriber moves out from TA list.

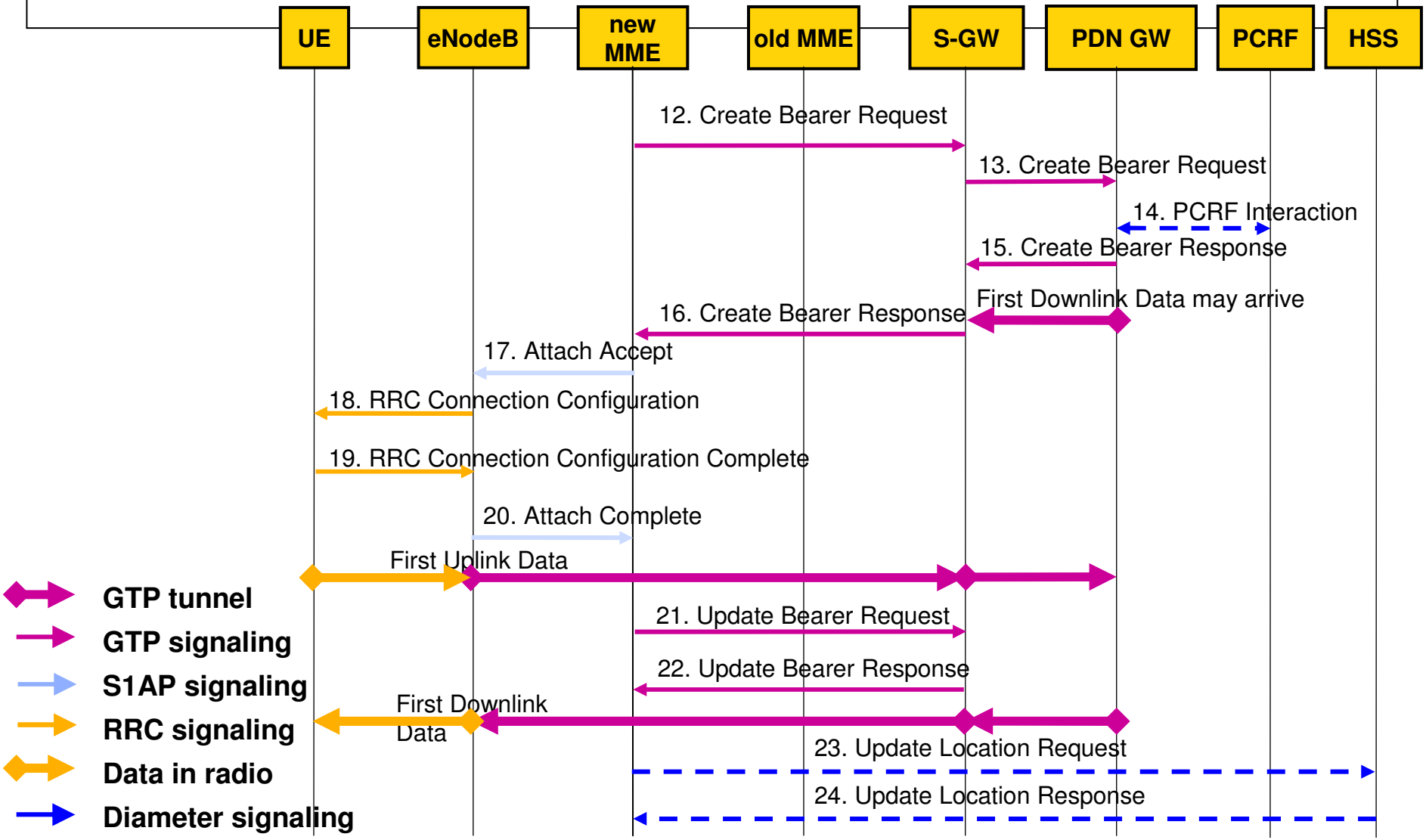
Paging

- UE is attached to the system and is in the ECM-IDLE state is traceable only to its registered TAs.
- Every time the EPC needs to contact such a UE, a paging procedure is initiated by MME.
- This action will provide the EPC with knowledge of the whereabouts of the UE (i.e. which cell it belongs to).
- There are a number of reasons why the network needs to initiate contact, the most common of which involves downlink data pending in the S-GW which needs to be delivered to the UE. Another reason is that the EPC may also want to establish C-plane connectivity for other reasons e.g. the network initiated TAU procedure or for location services.

Signaling flow – Attach (1/2)

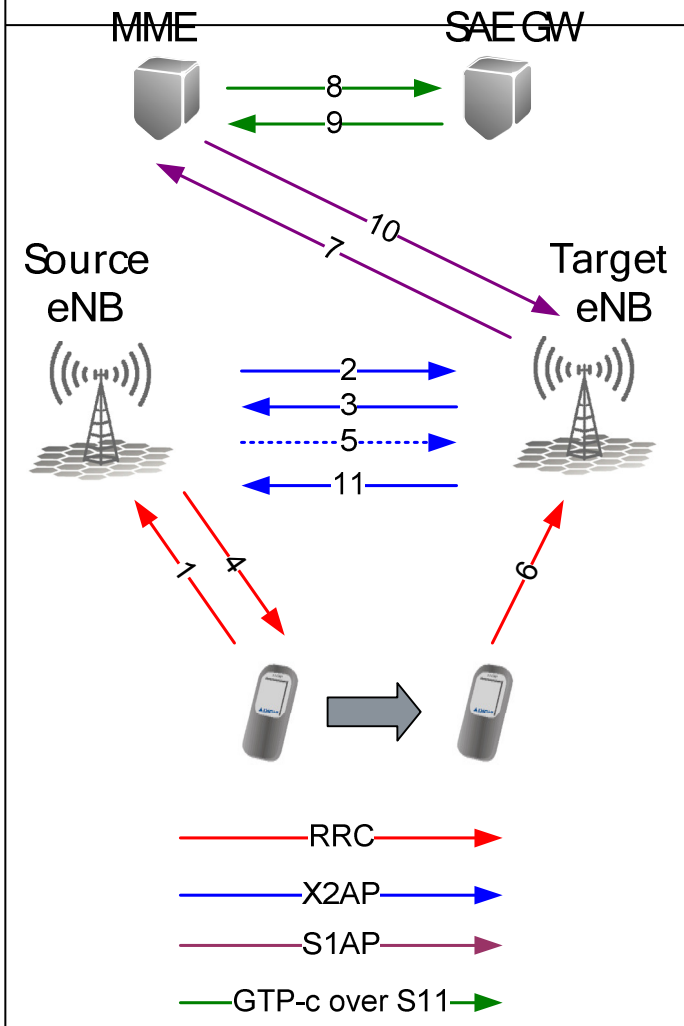


Signaling flow – Attach (2/2)



Signaling flow – X2 Handover

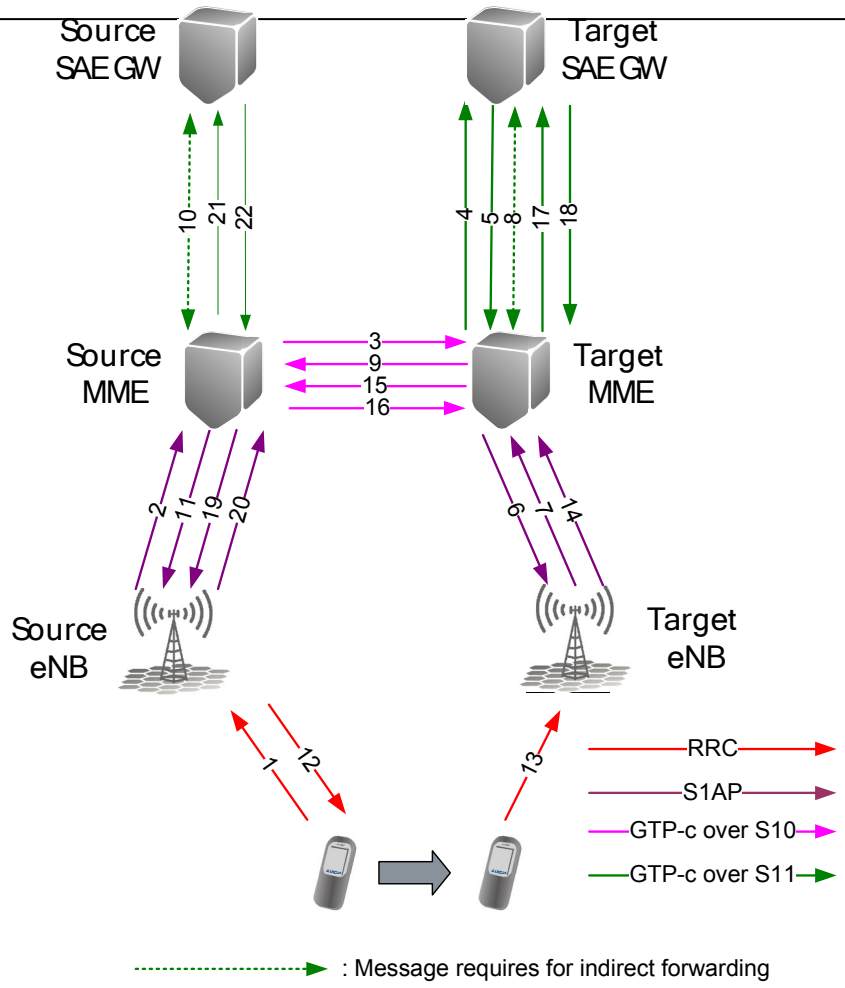
- Initiated by X2 message
- CN is involved after HO is completed -> less CN load
- Only applicable when
  - X2 interface is existing between two eNBs and
  - the two eNBs connect to same MME, i.e. in same MME pool area
- Less signaling -> less HO time
- Can be executed with S-GW relocation
- S1AP resource in Source eNB is locally release after reception of X2 message
- MME ID which source eNB connects is contained in X2:HO Request message
- End-marker is sent from S-GW at path swithcing for telling T-eNB the end of data forwarding via S-eNB.
- In case Source eNB receives DL NAS mesasge during HO, it sends failure message with the DL NAS message
- UL Data forwarding may be executed optionally.



Inter-eNB HO without CN node relocation

Signaling flow – S1 Handover

- Initiated by S1 message and CN is involved from beginning of HO
- Executed in case X2 HO is not executed, e.g.
  - X2 is not existing between two eNBs
  - The two eNBs do not connect to same MME
  - Inter-RAT
- Same approach with UMTS: SRNS Relocation
- Two data forwarding schemes
  - Direct: S-eNB -> T-eNB (e.g. in case X2 is available)
  - Indirect: S-eNB -> GW(s) -> T-eNB
- Source eNB is able to know that target eNB belongs to same MME pool beforehand by X2 message (optionally at X2 Setup phase).



Inter-eNB HO with CN node relocation

Mobility Management Procedures

Attach:

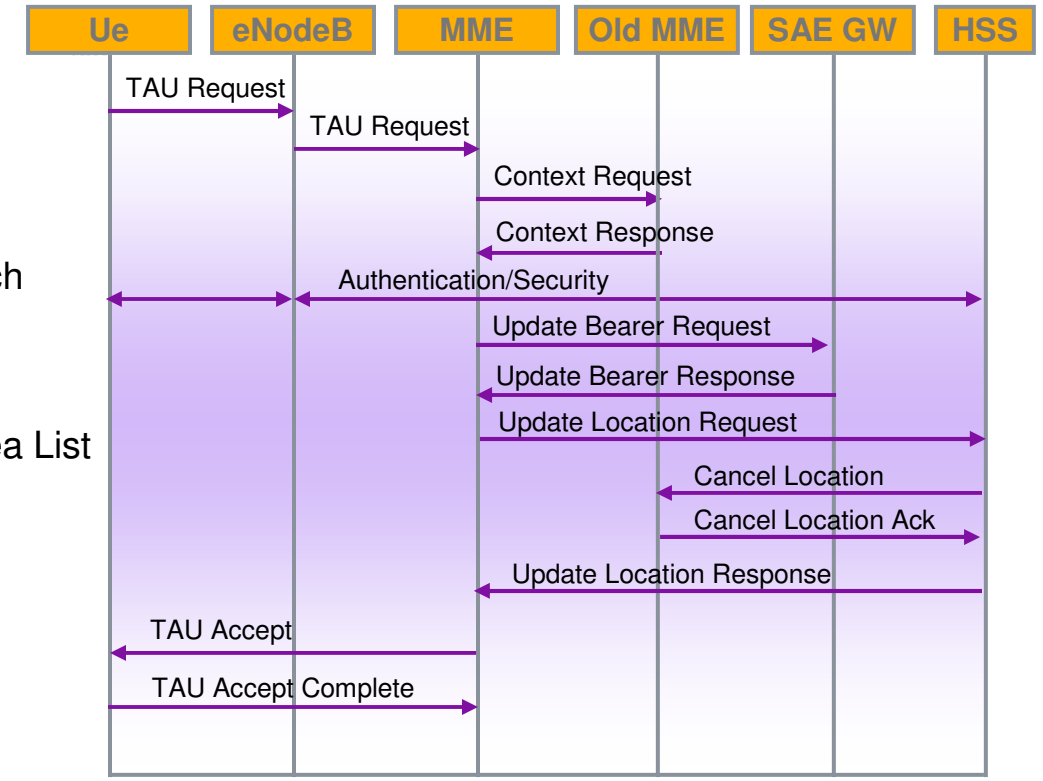
- UE needs to register to network
  - Identification
  - Authentication
  - Security
- Default EPS bearer is established during Attach
  - S-GW and P-GW selection

Tracking Area Update:

- UE enters a new TA that is not in Tracking Area List
  - MME/SGSN/S-GW change
  - Authentication/Security possible
  - S-GW updated
- Periodic TAU is needed
- Intersystem TAU/RAU

Service Request:

- Uplink data from UE
  - Radio and S1 bearer activated for all EPS bearers
- Downlink data from network
  - Paging
  - Service request from UE



TAU as an example Procedure

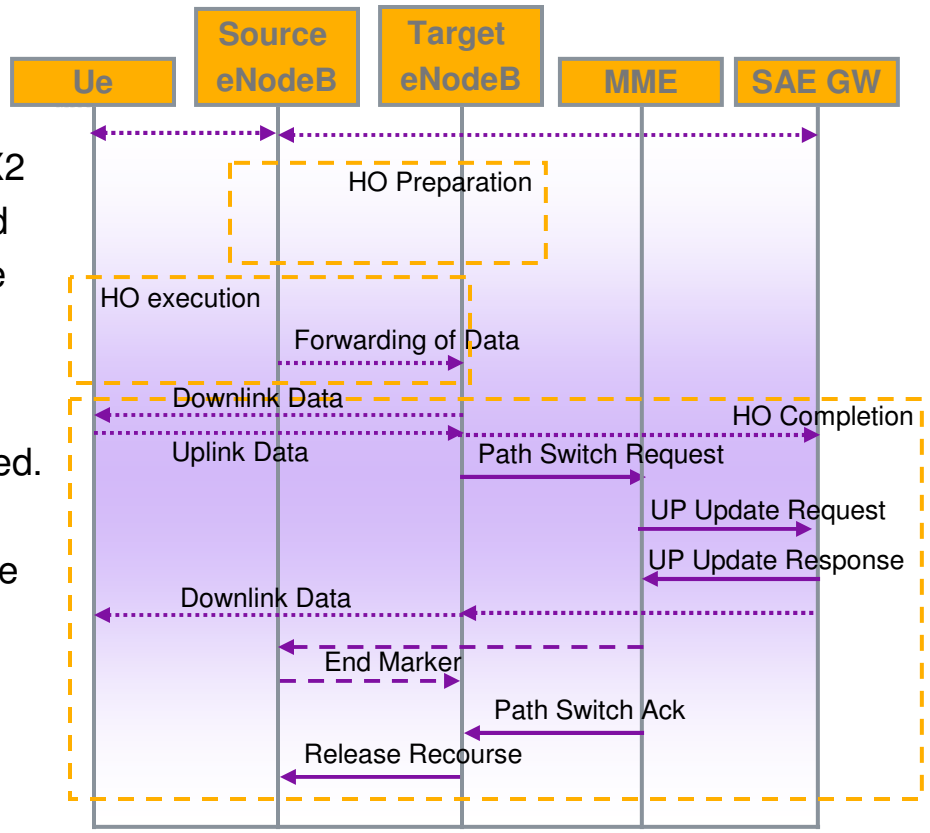
Mobility Management Procedures

Handover:

- X2 handover (X2 interface between eNodeBs)
  - UE Moves from eNodeB to eNodeB using X2
  - MME is not changed S-GW can be changed
  - eNodeBs makes preparation – MME update GW for downlink
- S1 handover
  - The S1-based handover procedure is used when the X2-based handover cannot be used.
  - No X2 interface or MME change
  - MME handle handover signalling and update S-GW
- Inter RAT handover
  - Relocation used in UTRAN
  - PS handover used in GERAN

Detach:

- UE-Initiated Detach Procedure
- MME-Initiated Detach Procedure
- HSS-Initiated Detach Procedure



X2 HO as an example Procedure

Mobility Management Procedures

S1 release:

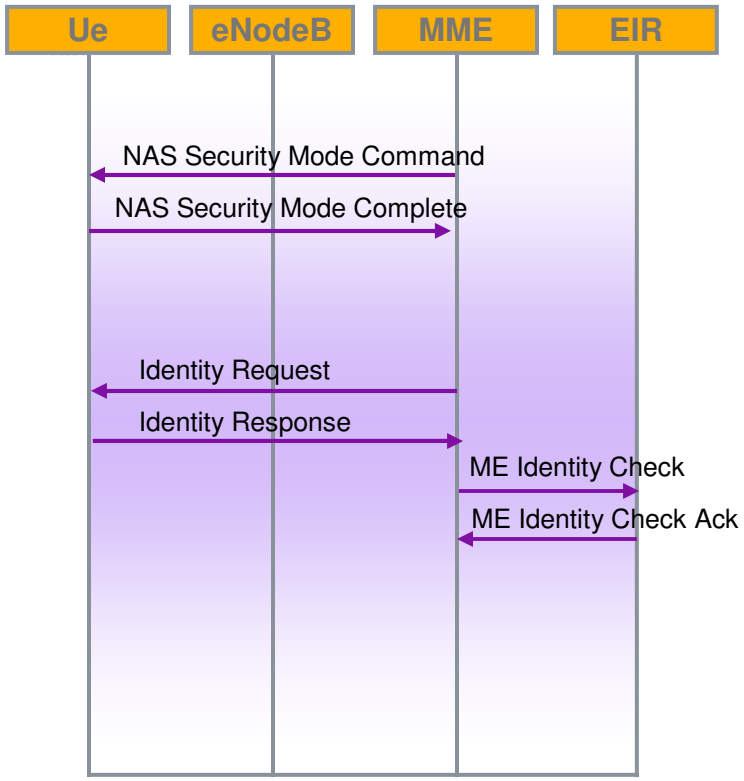
- It's used to release the logical S1-AP signalling connection and all S1 bearers
- It will move the UE from ECM-CONNECTED to ECM-IDLE

Security Functions:

- The security functions include:
  - Guards against unauthorised EPS service usage (authentication of the UE by the network and service request validation).
  - Provision of user identity confidentiality (temporary identification and ciphering).
  - Provision of user data and signalling confidentiality (ciphering).
  - Provision of origin authentication of signalling data (integrity protection).
  - Authentication of the network by the UE.

Session Management

- Bearer Activation
- Bearer Deactivation
- Bearer Modification



Example Security Functions

Security

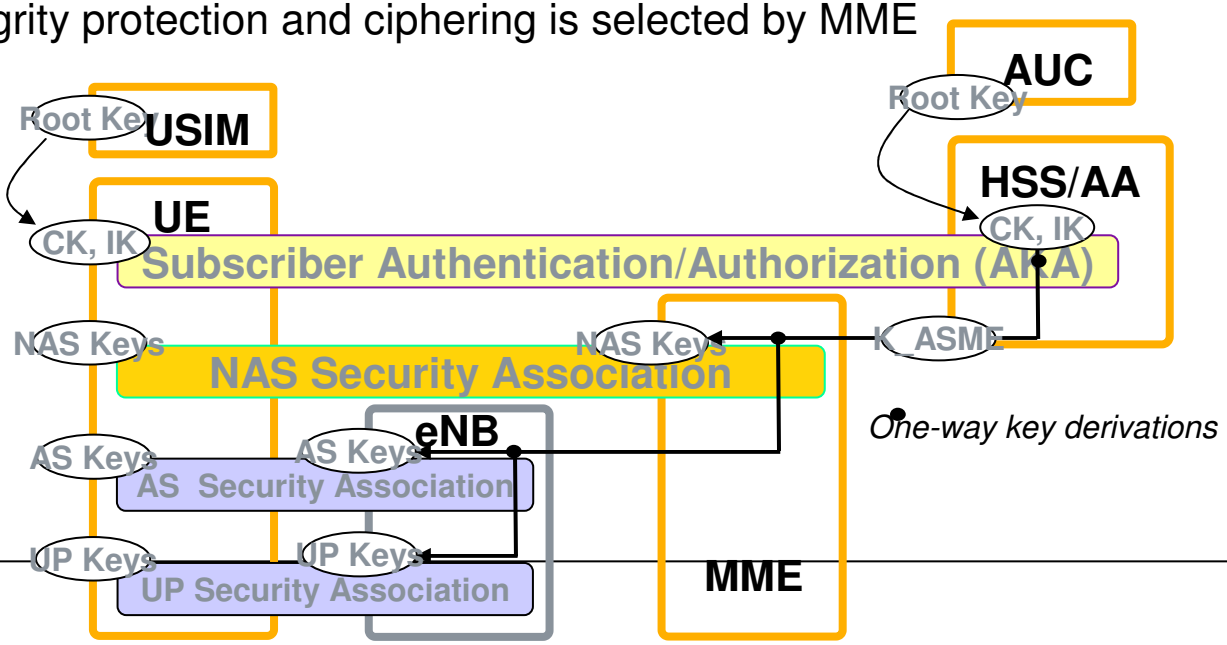
EPS Authentication and Key Agreement (AKA) is used

Two security associations exist between UE and EPS

- UE – eNB
- UE – MME

MME supports NAS security

- Integrity protection of NAS signalling messages
- Ciphering of NAS signalling messages
- Algorithm for integrity protection and ciphering is selected by MME



Mobility Management and Security - Summary

Mobility Management is visible in all elements

- MME – IDLE Mobility and Handovers
- S-GW – LTE and 3GPP user plane mobility
- P-GW – Mobility for non 3GPP interworking

Mobility Management states

- EMM-DEREGISTERED - The UE is not reachable by a MME
- EMM-REGISTERED - The UE location is known and UE has at least one PDN connection
- ECM-IDLE - No NAS signalling connection between UE and network
- ECM-CONNECTED – Signalling connection between the UE and the MME

Mobility Management Procedures

- IDLE mobility – TAU inside of LTE
- Handover – X1 and S1 handover for different scenarios
- Intersystem Mobility – For Idle mobility TAU/RAU and for handover Relocation/PS handover

Security

- Several levels of security -
- NAS Ciphering for signaling – AES and Snow3G
- Authentication and keys – SRES=XRES comparison, K_{ASME} is the root of the key hierarchy

Session Management & QoS

Session Management and QoS Principles

- Network controlled bearer and QoS management
- Continuation of 3G bearer model
- Always On
- Reduced set of QoS parameters
- Standardized QoS characteristics
- For each bearer, QoS support is based on QoS parameters
  - Available in subscriber profile
  - Controllable by network
- Minimizing QoS knowledge and configuration in UE

Session Management & Bearer Types

Two types of EPS bearers exist: default bearers (similar to primary PDP contexts) and dedicated bearers (similar to secondary PDP contexts BUT fully EPC controlled)

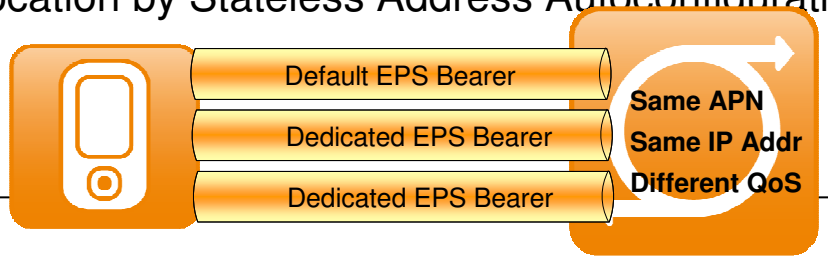
- First default bearer is created when UE attaches to EPC and remains active as long as UE is attached to EPC
- Dedicated bearers are created for QoS differentiation purposes - creation of dedicated bearers is controlled by EPC

Three PDN Types exist

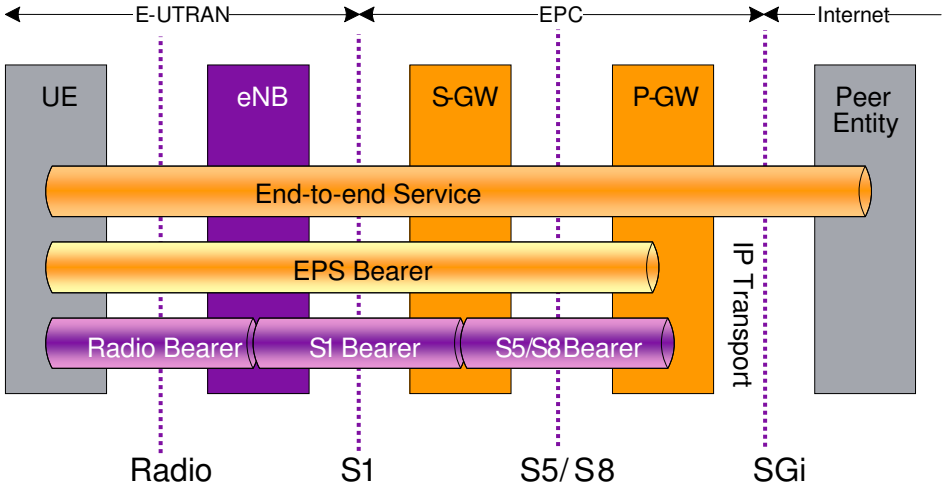
- IPv4 – bearer capable of carrying IPv4 traffic
- IPv6 – bearer capable of carrying IPv6 traffic
- Dual Stack - bearer capable of carrying both IPv4 and IPv6 traffic (new PDN Type introduced in 3GPP R8)

For IP address allocation, three mechanisms exist

- IPv4 address allocation with EPS signalling
- IPv4 address allocation by DHCPv4
- IPv6 address allocation by Stateless Address Autoconfiguration

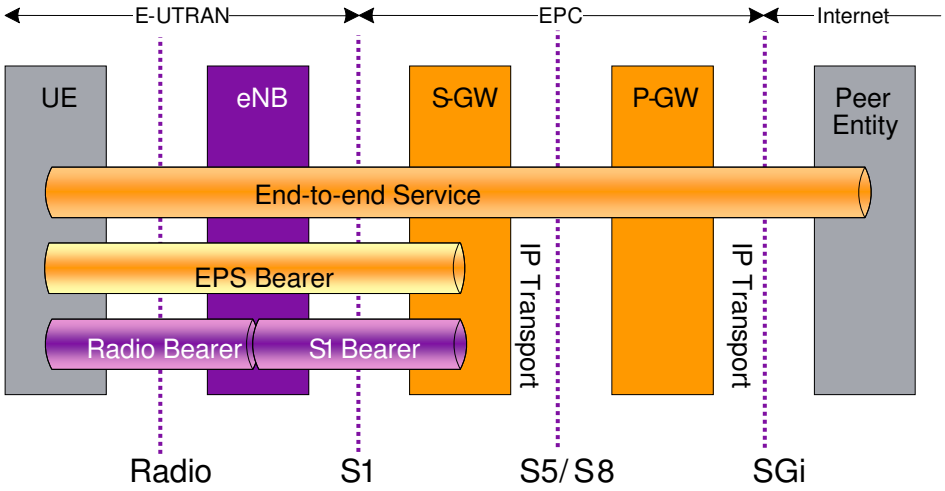


Bearer model in GTP and IETF variants



GTP variant:

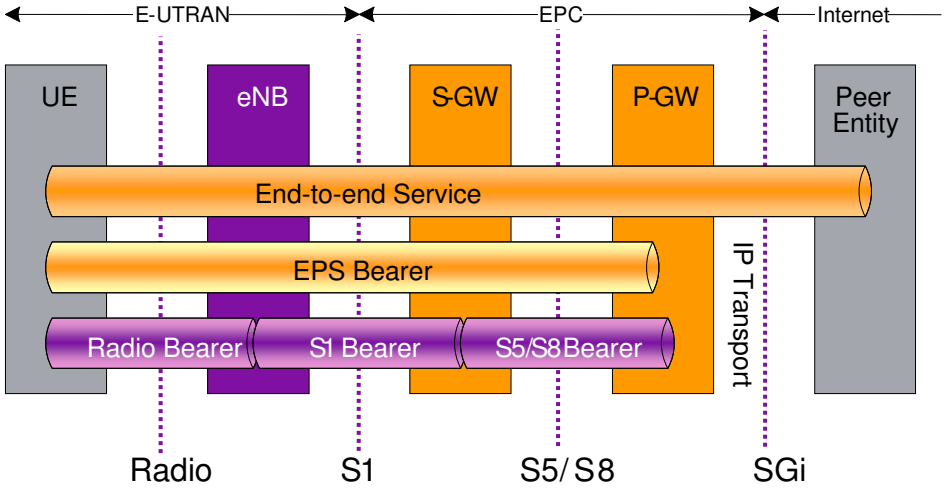
EPS bearer termination in PGW



IETF variant:

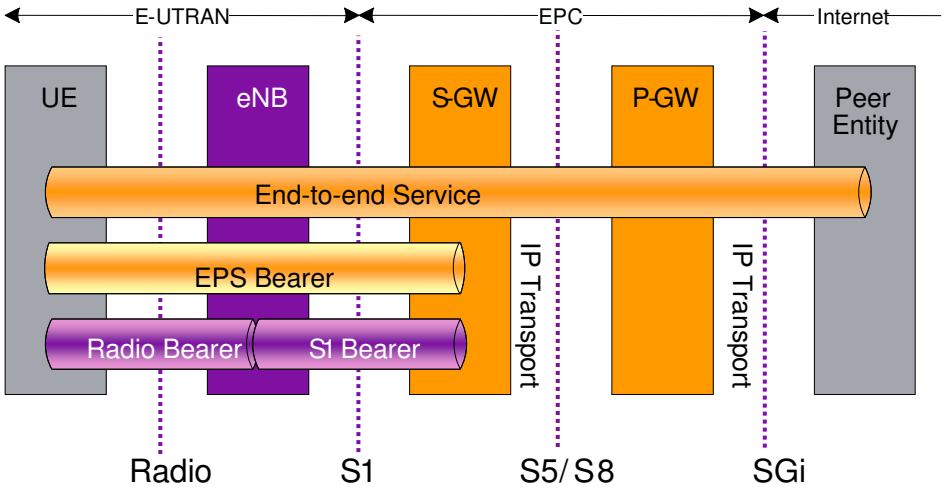
EPS bearer termination in SGW

Bearer model in GTP and PMIP (IETF) variants



GTP variant:

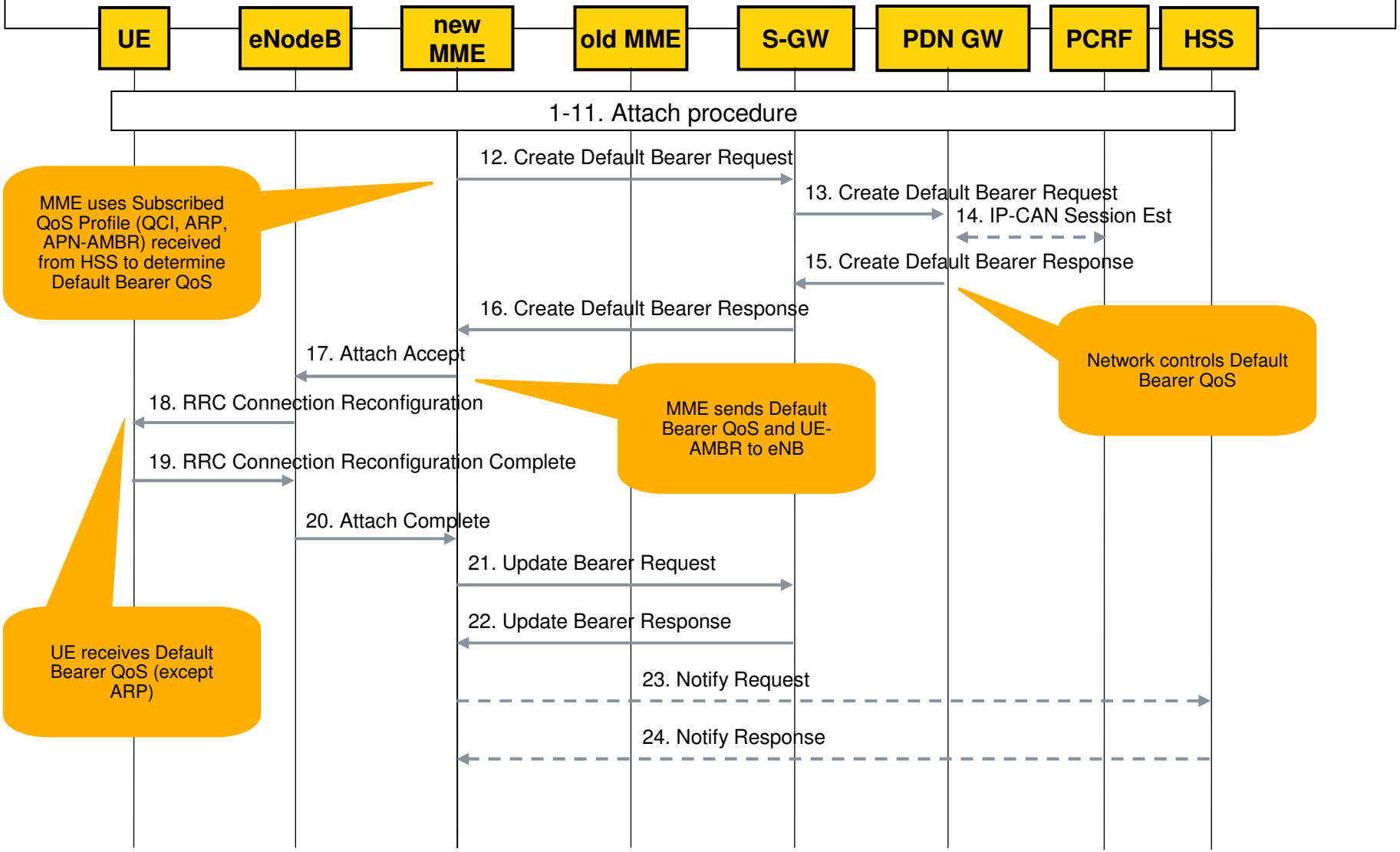
- EPS bearer termination in PGW
- PDN GW handles user plane packets on bearer level, e.g. QoS, charging, and IP flow level when that is supported
- GTP used in EPC (GTPv2-C, GTPv1-U), also for S5/S8 interface



PMIP variant:

- EPS bearer termination in SGW
- PDN GW handles user plane packets on IP flow level
- PCC infrastructure is very important in conveying many parameters
- GTP used in EPC (GTPv2-C, GTPv1-U) except for S5/S8 interface PMIP is used

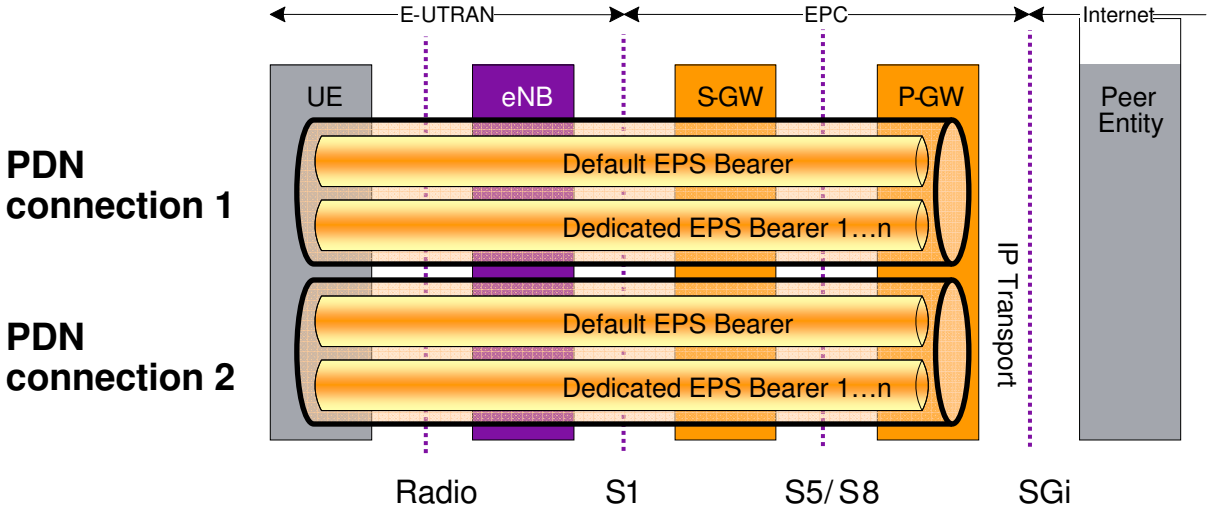
Default bearer activation at attach (GTP variant)



session creation

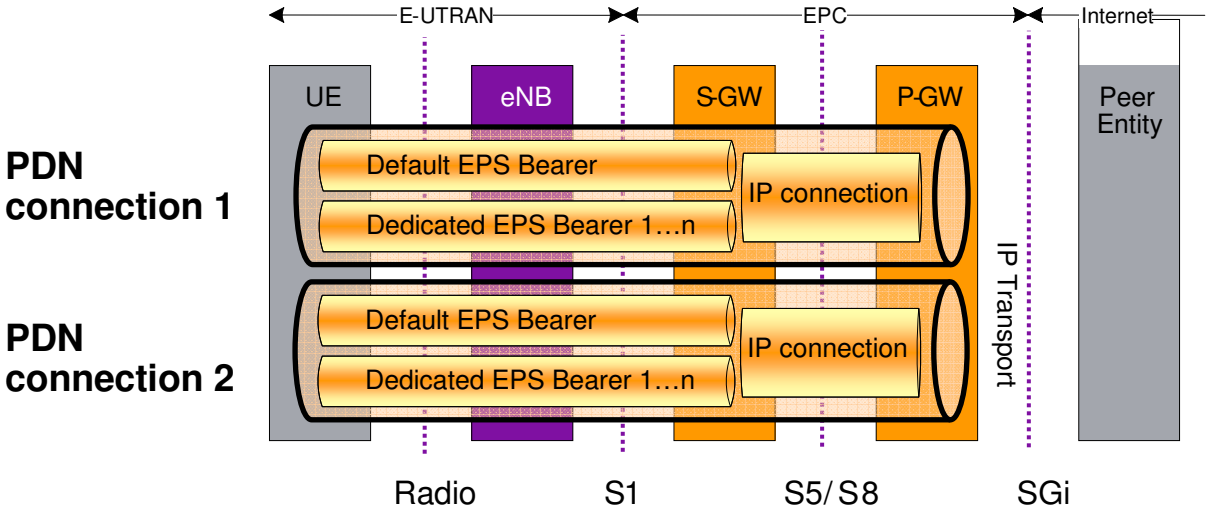
- UE sends an Attach Request to the MME
- MME sends an Update Location Request to the HSS
- HSS sends back an Update Location Ack which includes subscription data. The data contains one or more PDN subscription contexts and each context contains subscriber APN-AMBR (per APN). The data also contains UE-AMBR.
- MME selects one PDN context for the UE and sends the APN-AMBR from this context to the S-GW in the Create Session Request message.
- S-GW creates a new entry in the EPS Bearer table and send the APN-AMBR to the P-GW in the Create Session Request message.
- P-GW – PCRF interaction may change the APN-AMBR. APN-AMBR is sent back to S-GW in the Create Session Response message.
- S-GW sends APN-AMBR to the MME in the Create Session Response message.
- MME determines the UE-AMBR to be used by the eNB based on the subscribed UE-AMBR and the APN-AMBR for the default APN. The MME (CPPU unit) gets the number of active APNs for the UE and the sum APN-AMBR associated with each APN.
- UE-AMBReNB = MIN (∑APN-AMBR, UE-AMBRHSS)
- MME includes APN-AMBR in the Active Default Bearer Request message to the UE and the UE-AMBReNB in the Initial Context Setup Request message to the eNB.
- MME also sends APN-AMBR associated with the APN to the UE in the Activate Default Bearer Request message (session management).

PDN connections and bearers in GTP and IETF variants



GTP variant:

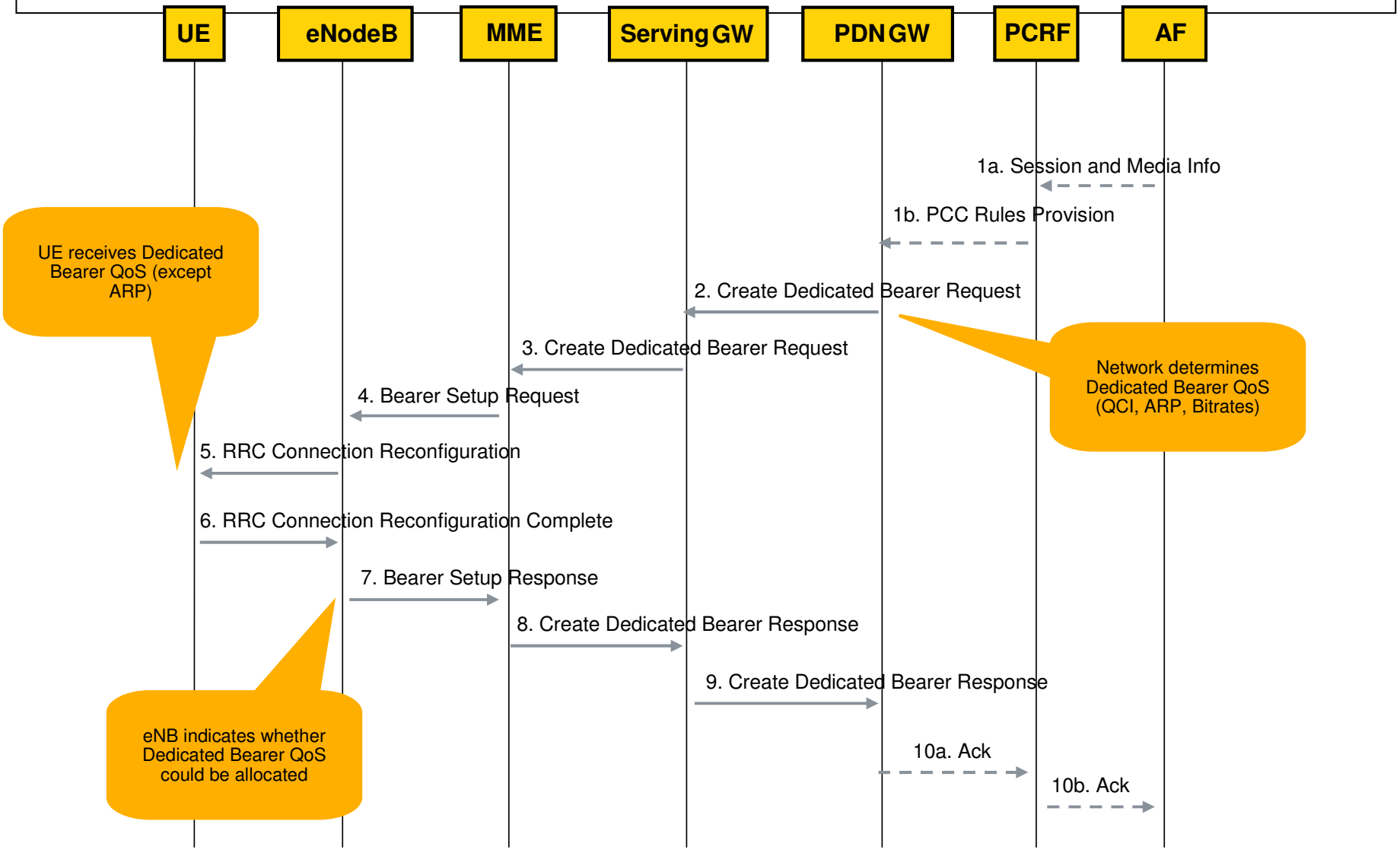
EPS bearer termination in PGW



IETF variant:

EPS bearer termination in SGW

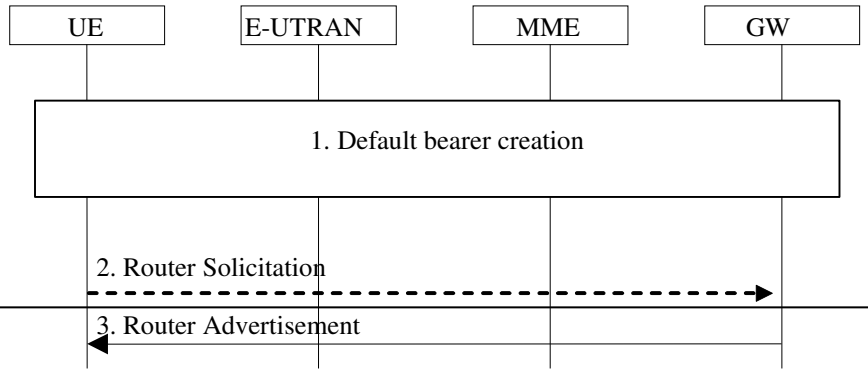
Dedicated bearer activation (GTP variant)



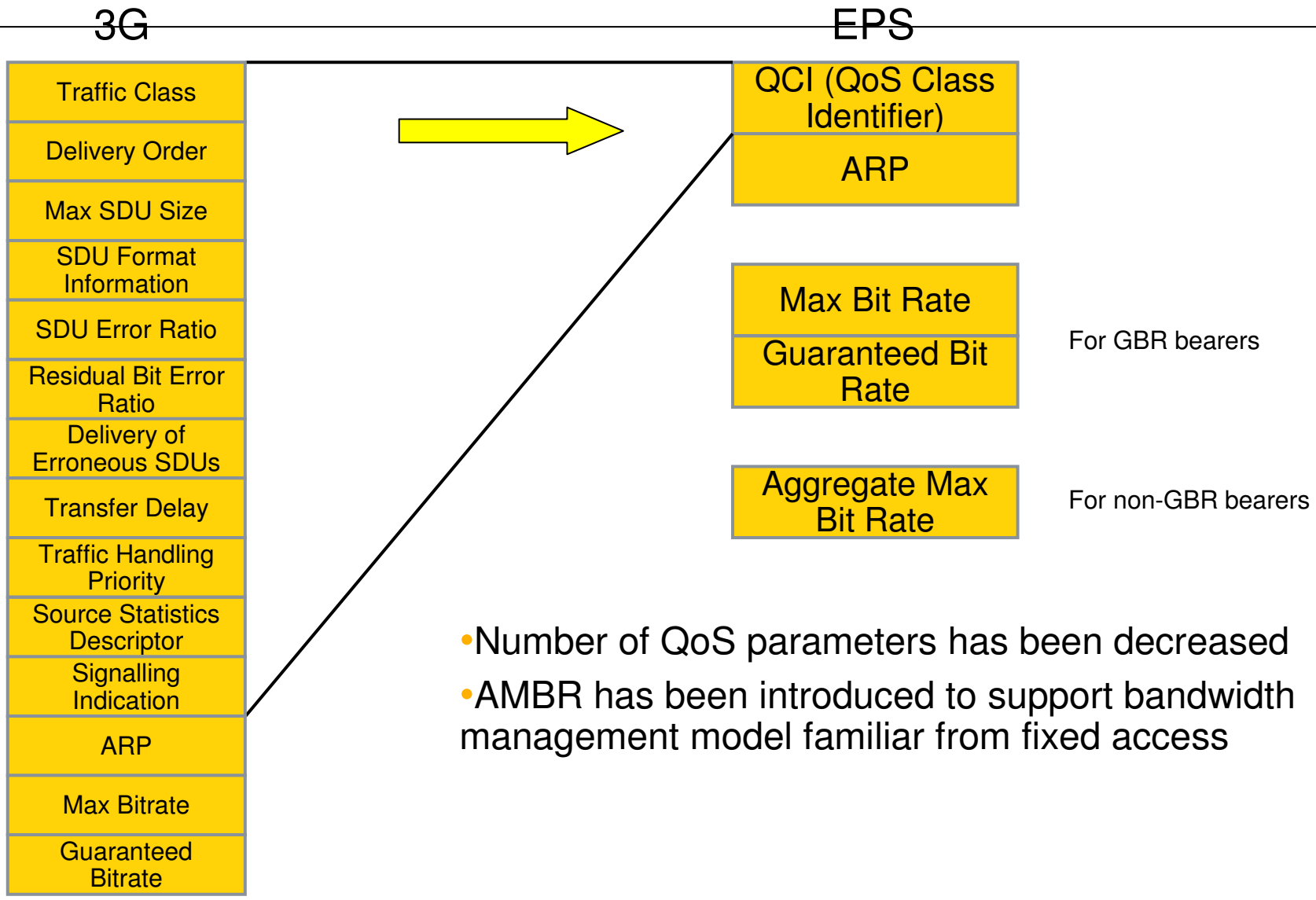
IP address allocation

- Depending on bearer type, IPv4 or IPv6 or both may be allocated to a default bearer and related dedicated bearers
- Both static and dynamic addresses are supported
- IPv4 address allocation
  - Mandatory: IPv4 address allocation via EPS signalling at default bearer creation
  - Optional: DHCPv4
- IPv6 address allocation

Mandatory: IPv6 stateless address autoconfiguration



Simplifications in QoS profile

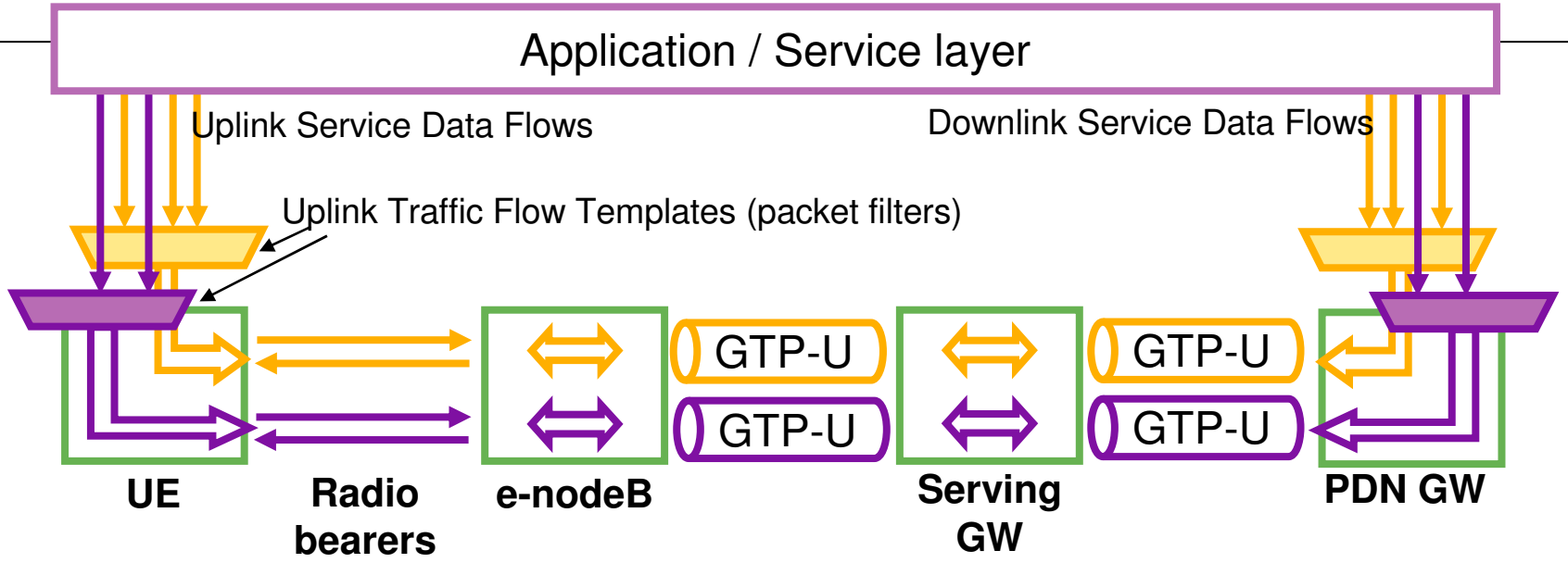


- Number of QoS parameters has been decreased
- AMBR has been introduced to support bandwidth management model familiar from fixed access

QoS parameters in EPS

- **QoS Class Identifier (QCI)**
  - QCI is used to determine packet forwarding treatment (e.g. scheduling of packets)
  - QCI can be used to mark packets with DSCP
  - 3GPP has standardised 9 QCI values and mapping to resource type (GBR, non-GBR), priority, packet delay budget and packet error loss rate
- **Allocation and Retention Priority (ARP)**
  - ARP is used to decide whether bearer establishment or modification request can be accepted in case of resource limitations
  - ARP can also be used to decide which bearer(s) to drop during resource limitations
  - It has been agreed in 3GPP that ARP has no impact on packet forwarding treatment
- **APN Aggregate Max Bit Rate (APN-AMBR) and UE Aggregate Max Bit Rate (UE-AMBR) for non-GBR EPS bearers**
  - APN-AMBR shared by all non-GBR EPS bearers with the same APN – downlink enforcement is done in PDN GW and uplink enforcement in UE
  - UE-AMBR shared by all non-GBR EPS bearers of the UE – downlink and uplink enforcement is done in eNB
- **Guaranteed Bit Rate (GBR) and Max Bit Rate (MBR) for GBR EPS bearers**

Evolved Packet System (EPS) bearers (1/2)



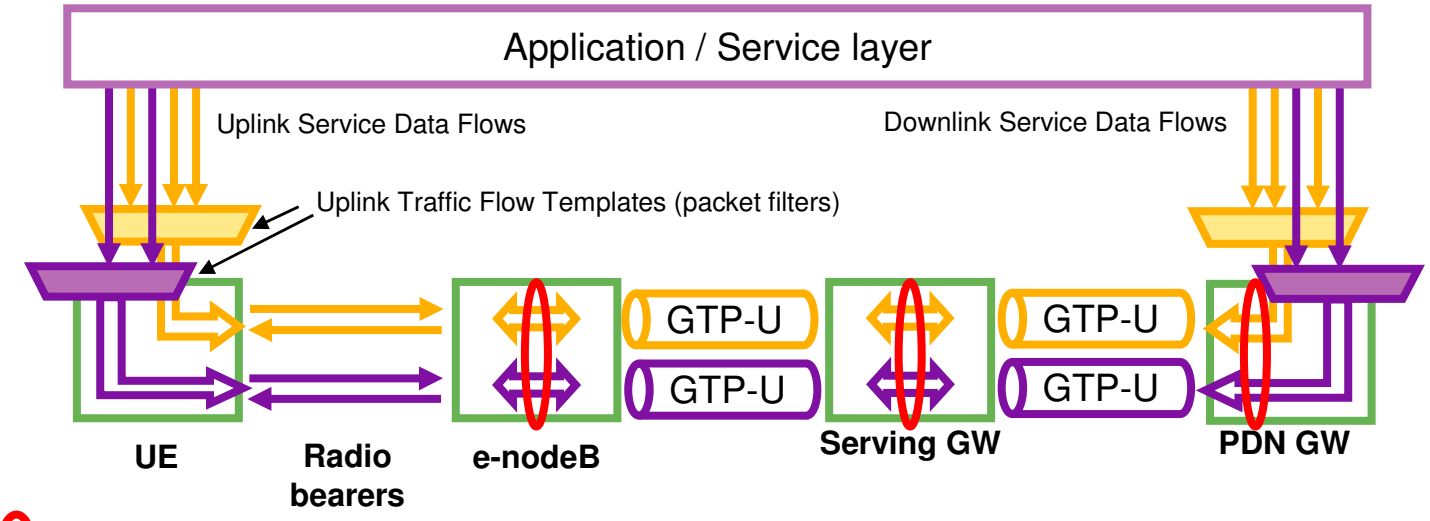
- EPS Bearer in LTE/SAE corresponds to PDP context in 2G/3G networks
- Default Evolved Packet System (EPS) bearer's Traffic Flow Template (TFT) matches all packets
  - Default bearer is Non-guaranteed Bit Rate and always on
- Dedicated EPS bearer's TFT match only certain packets
  - Dedicated bearers are setup on network request for e.g. VoIP calls
  - Policy and Charging Rules Function (PCRF) communicates with Policy and Charging Enforcement Function (PCEF) within PDN GW to determine the bearer QoS
  - Default QoS rules can alternatively be configured PDN GW for situations when the PCRF does not give instructions

Evolved Packet System bearers (2/2)

- Traffic Flow Templates are initiated from the network
- Only the PDN GW and UE have flow specific information.
  - Between these, the packets are carried in default or dedicated bearers
  - The application layer is non-QoS aware
- The following parameters are signaled between from PDN GW to eNode-B:
  - Label
  - Guaranteed Bit Rate (uplink/downlink)
  - Maximum Bit Rate (uplink/downlink)
  - Allocation/Retention Priority (connection setup priority among subscribers when the network is congested)
- A limited number of label characteristics (parameter value combinations) will be standardized
  - A label includes: Bearer type (Guaranteed or non-guaranteed Bit Rate), Packet Delay and Packet Loss values
  - Label is a numerical value that indicates to the PDN GW which values are applied
- Admission Control is applied for radio bearers and in the core elements to provide bandwidth guarantees
- Access Point handling is similar to 2G/3G

Subscriber specific Aggregate Maximum Bitrate

- Subscriber specific Aggregate Maximum Bitrate (AMBR) is applied to limit the capacity allocated for a single user
  - Multiple EPS bearers of the same UE share the same AMBR
  - Any single EPS bearer can potentially utilize the entire AMBR, e.g. when the other EPS bearers do not carry any traffic
  - AMBR applies only to Non-GBR bearers of a UE



= e-nodeB and gateways monitor and police (enforce) the AMBR

QoS functions

- QoS functions have not been standardised in detail in 3GPP but are implementation specific
- QoS functions
  - Admission control
  - Bandwidth management based on APN-AMBR and UE-AMBR
  - Bearer level bandwidth management
  - Service level bandwidth management
  - Bearer level DSCP marking
  - Service level DSCP marking
  - Queueing and scheduling of packets

Benefits of LTE QoS implementation

- QoS is defined between the two end entities: the user equipment and PDN Gateway
- QoS label applies between UE and PDN Gateway for 3GPP and non-3GPP accesses
- Labels can be agreed between operators
  - Necessary labels will be standardized; operators can apply own label value combinations on top of those
  - A label corresponds to the needs of a certain service, for example VoIP
  - Improves interoperability between different operators

Standardized QCIs

QCI	Resource type	Priority	Packet delay budget	Packet error loss rate	Example Application
1	GBR	2	100 ms	1e-2	Conversation voice
2	GBR	4	150 ms	1e-3	Conversational video
3	GBR	3	50 ms	1e-3	Real-time gaming
4	GBR	5	300 ms	1e-6	Non-conversational video
5	Non-GBR	1	100 ms	1e-6	IMS signalling
6	Non-GBR	6	300 ms	1e-6	Video, www, email, ftp
7	Non-GBR	7	100 ms	1e-3	Interactive gaming
8	Non-GBR	8	300 ms	1e-6	Video, www, email, ftp
9	Non-GBR	9	300 ms	1e-6	Video, www, email, ftp

Note: Usage of operator specific QCIs in addition to standardized QCIs is possible.