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# QoS in LTE
# PSCR Demo Days

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# Introduction

This talk covers the following areas which are key to providing Public Safety with the required Quality of Service (QoS) and Priority Access

1. Control Access to Air Interface
   - Access Class barring
   - Establishment cause
2. Control Use of Resources
   - ARP
   - QCI
   - Policy rules
3. Roaming/Handover Implications
4. VPN Implications

Adherence to standards in these areas will be key to interoperability

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# 1 Control Access to Air Interface

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# Control Access to Air Interface
## Access Class Barring - Priority Access in LTE

- **What is it?**
  - Mechanism to discourage regular users from accessing a cell
  - Only applies to mobile originations
  - Typical use:
    - Reserve cells for operator activities – maintenance, growth, etc.
    - Reduce access overload in time of emergency or congestion
  - Work ongoing in 3GPP R10 to account for machine-to-machine traffic
- **Access control using access classes:**
  - Access class stored in USIM of device
    - Classes 0-9 randomly assigned to commercial users
    - Class 10 -> E911 calls
    - Classes 11 & 15 are reserved for network administrative devices
    - Remaining classes for Public Safety & NGN GETS users
      - Class 12 – Security Services (police, …)
      - Class 13 – Public Utilities ((water, gas, …)
      - Class 14 – Emergency Services (fire, EMT, ..)
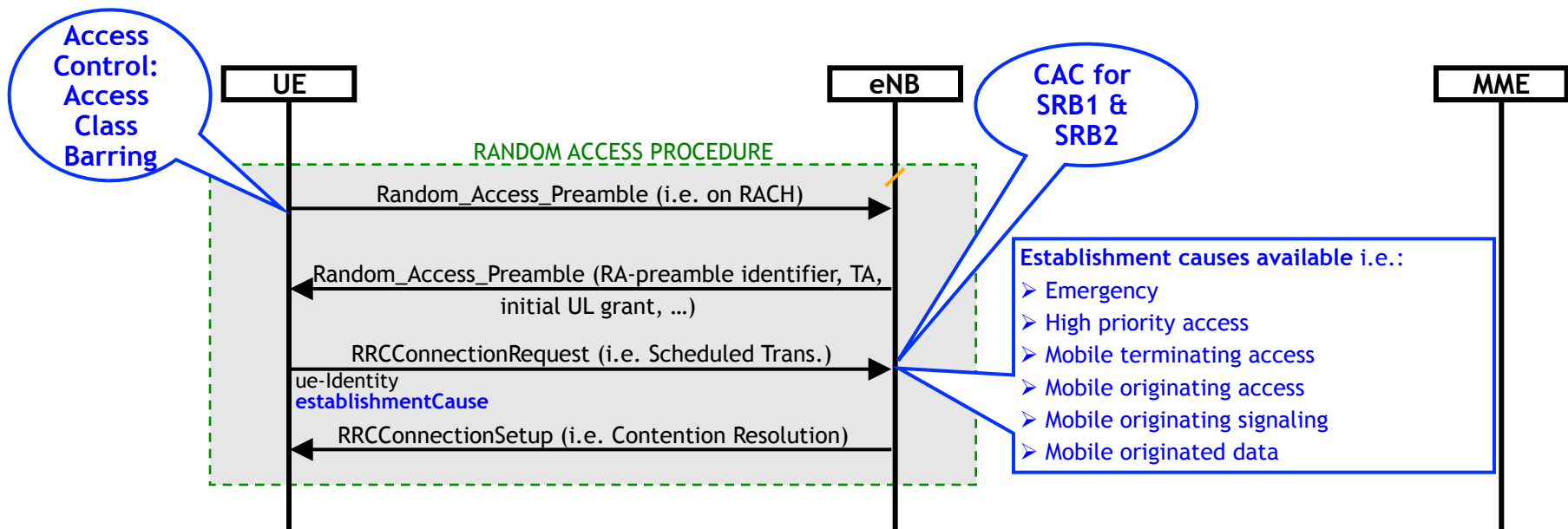
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# Control Access to Air Interface
## Access Class Barring - Definition in 3GPP

- eNodeB controls user access through broadcast of access class barring parameters in SIB2 and UE performs actions according to Access Class in USIM

- SIB2 (SystemInformationBlockType2) parameters for access control:
  - For regular users with AC 0 – 9, their access is controlled by ac-BarringFactor and ac-BarringTime
    - "Rand" generated by the UE has to pass the "persistent" test in order for the UE to access. By setting ac-BarringFactor to a lower value, the access from regular user is restricted (UE must generate a "rand" that is lower than the threshold in order to access) while priority users with AC 11 – 15 can access without any restriction
  - For users initiating emergency calls (AC 10) their access is controlled by ac-BarringForEmergency – boolean value: barring or not
  - For UEs with AC 11- 15, their access is controlled by ac-BarringForSpecialAC - boolean value: barring or not.  The standard defined these AC as follows (22.011, section 4.2):
    - Class 15 - PLMN Staff;
    - Class 14 - Emergency Services;
    - Class 13 - Public Utilities (e.g. water/gas suppliers);
    - Class 12 - Security Services;
    - Class 11 - For PLMN Use

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# Air Interface Priority
## Establishment Cause

- The "RRCConnectionRequest" from an NGN GETS or PS subscribed UE contains the EstablishmentCause, which when set to "highPriorityAccess" is a way for the eNB to prioritize RRC request
  - The Establishment Cause marked as "highPriorityAccess" indicates that the access request is originated from a UE operating as AC 11-15

**Access Control: Access Class Barring**

| UE | | eNB | | MME |
|---|---|---|---|---|

**CAC for SRB1 & SRB2**

RANDOM ACCESS PROCEDURE

Random_Access_Preamble (i.e. on RACH) →

← Random_Access_Preamble (RA-preamble identifier, TA, initial UL grant, …)

RRCConnectionRequest (i.e. Scheduled Trans.) →
ue-Identity
**establishmentCause**

← RRCConnectionSetup (i.e. Contention Resolution)

**Establishment causes available** i.e.:
- Emergency
- High priority access
- Mobile terminating access
- Mobile originating access
- Mobile originating signaling
- Mobile originated data

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# 2 Control Use of Resources

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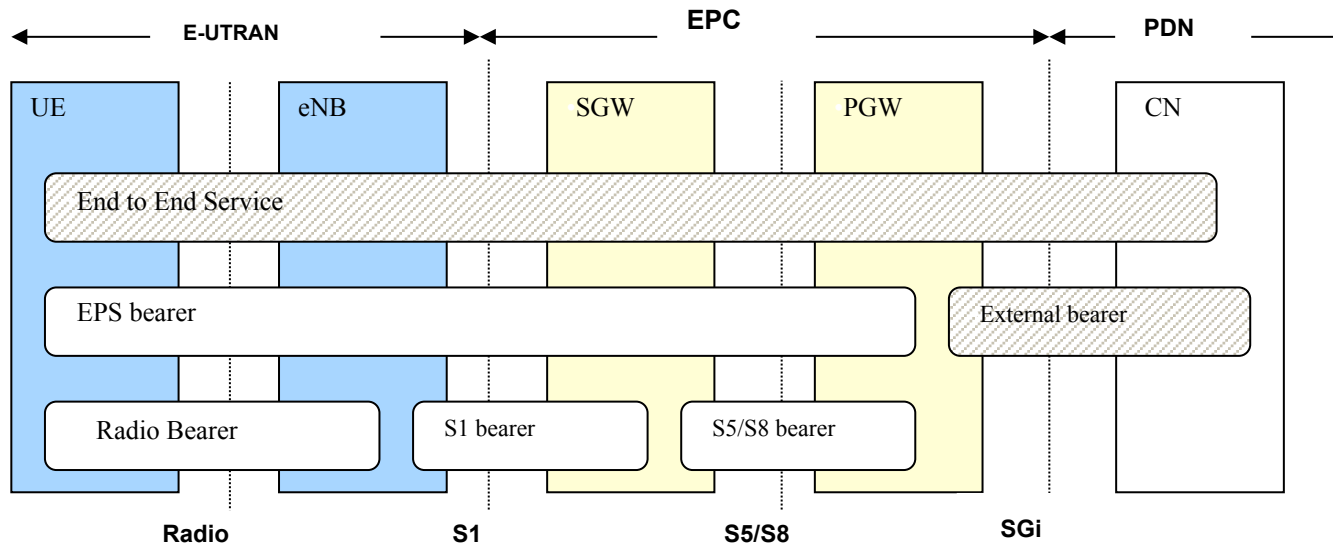
# Control Use of Resources
## Evolved Packet System (EPS) Bearer Management

- **EPS bearers provide the UE access to PDN services and associated applications**
  - Typically a Default Bearer is established during attachment, & maintained throughout the lifetime of the connection (always-on IP connectivity)
    - This is no guarantee for service access; it merely is reservation of resources before packet flows are admitted in the system
  - Additional Dedicated Bearers can be established, dynamically, as a result of service requests or access to services

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# Control Use of Resources
## EPS Bearer Management – Two Types of Bearers

### Guaranteed Bit Rate (GBR)

- Specified Guaranteed Bit Rate (GBR) and Maximum Bit Rate (MBR)

  - Note currently MBR=GBR (3GPP)

- Has associated ARP and QCI

- Service will not experience congestion-related packet loss (provided that the user traffic is compliant to the agreed GBR QoS parameters)

- Established on demand because it allocates transmission resources by reserving them during the admission control function

- Precedence of service blocking over service dropping in congestion situation

- Inactivity timers are used to control air interface and S1 interface to free up resources

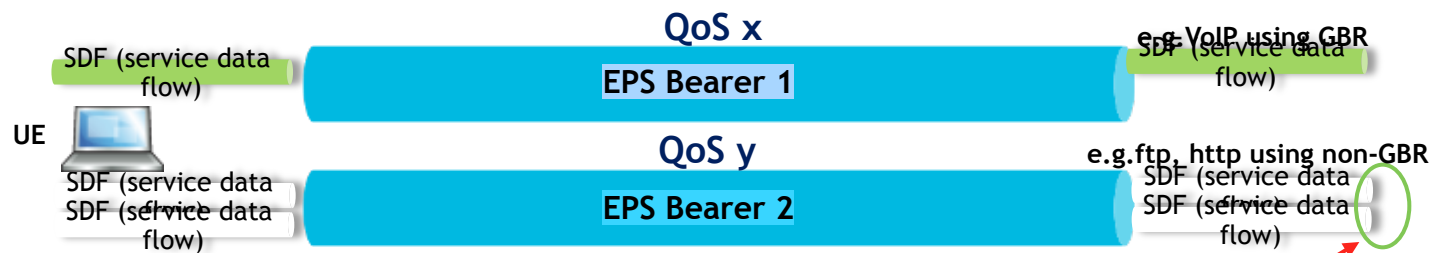### Non-Guaranteed Bit Rate (Non-GBR)

- May have a Maximum Bit Rate (MBR)

- Has associated ARP and QCI

- Service must be prepared to experience congestion-related packet loss

- Can remain established for long periods of time because it does not reserve transmission resources

- Precedence of service dropping over service blocking in congestion situation

- Stay up (no reserved resources)

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# Control Use of Resources

## Evolved Packet System QoS Parameters

## Per bearer (or bearer aggregate) QoS parameters

- QoS Class Identifier (QCI)
  - To control packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and typically pre-configured by the operator
- Allocation and Retention Priority (ARP) ← *For admission control, i.e. not used by eNodeB scheduler*
  - The primary purpose or ARP is to decide if a bearer establishment/modification request can be accepted or rejected in case of resource limitation
- Guaranteed Bit Rate and Maximum Bit Rate – Per GBR bearer
- Aggregate Maximum Bit Rate (AMBR) – Sums all <u>non-GBR</u> bearers per terminal/Access Point Name (APN)

**QoS x**

SDF (service data flow)

EPS Bearer 1

e.g. VoIP using GBR
SDF (service data flow)

UE

**QoS y**

SDF (service data flow)
SDF (service data flow)

EPS Bearer 2

e.g.ftp, http using non-GBR
SDF (service data flow)
SDF (service data flow)

all flows get similar treatment (scheduling policy, queue management policy, etc.)

Traffic Filter Templates at both UE and PGW are responsible for distributing SDFs between EPS bearers
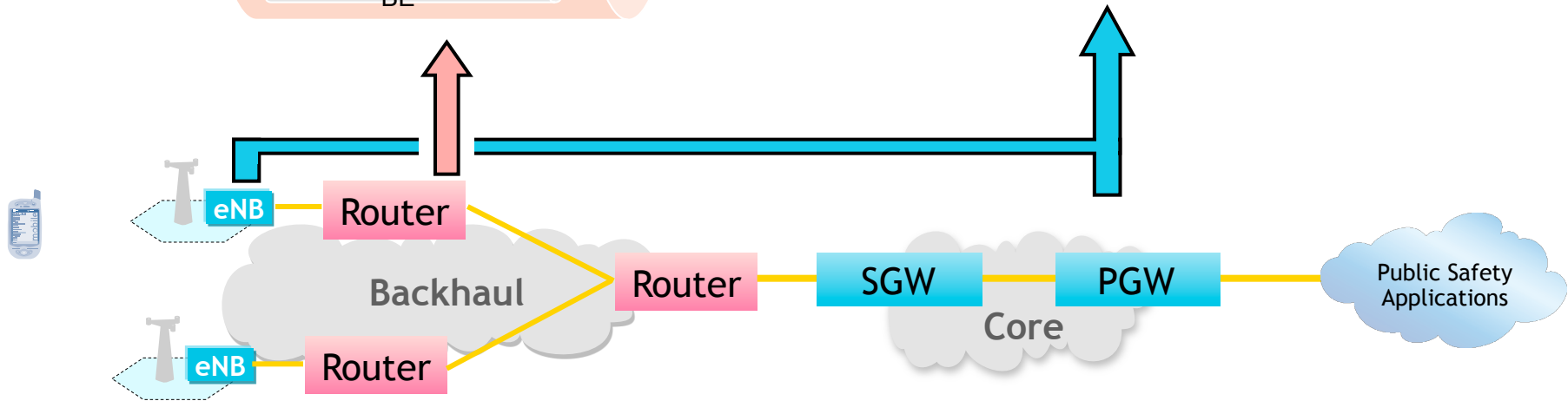
*EPS or Evolved Packet System is the eUTRAN + EPC (radio + core) combination

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# Control Use of Resources

## Mapping applications to LTE QoS Classes (QCIs): The 3GPP view
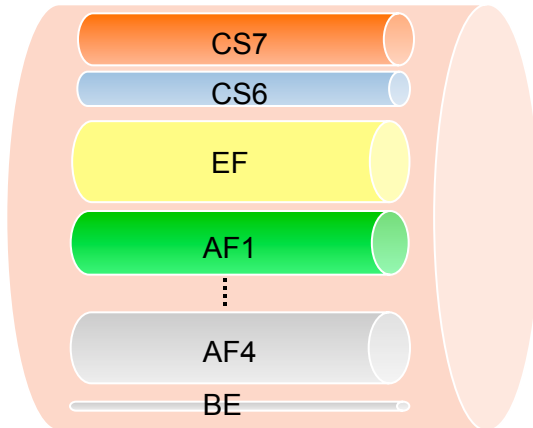
| QCI | Priority | Service Example |
|---|---|---|
| 1 (GBR) | 2 | Conversational Voice |
| 2 (GBR) | 4 | Conversational Video |
| 3 (GBR) | 3 | Robotics |
| 4 (GBR) | 5 | Streaming Video |
| 5 (non-GBR) | 1 | IMS Signalling |
| 6 (non-GBR) | 6 | www, e-mail, chat, ftp, p2p file sharing, etc.) |
| 7 (non-GBR) | 7 | Voice, Video (Live Streaming), Interactive Gaming |
| 8 (non-GBR) | 8 | www, e-mail, chat, ftp, p2p file sharing, etc.) |
| 9 (non-GBR) | 9 | www, e-mail, chat, ftp, p2p file sharing, etc.) |

CS7

CS6

EF

AF1

AF4

BE

eNB — Router

Backhaul

Router — SGW — PGW — Core

eNB — Router

Public Safety Applications

- The PGW maps traffic onto EPC bearers (associated with QCIs) which are mapped onto DiffServ Classes; re-marks packets' IP header to reflect priorities as close as possible

- During congestion, core and backhaul routers drop packets according to DSCP

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# Control Use of Resources
## Admission Control – Allocation Retention Priority (ARP)

- ARP is stored in the Subscriber profile (HSS) on a per APN basis (at least one APN must be defined per subscriber) and consists of:
  - Priority level: 1 – 15, with 1-8 intended for prioritized treatment within operator domain (per 3GPP 29.212, Section 5.3.45)
    - NGN GETS recommends reserving 1 to 5 ARP levels in the range of 1-8 to represent the 5 NGN GETS priority levels
  - Pre-emption capability flag: can pre-empt other users
  - Pre-emption vulnerability flag: can be pre-empted by other users
- At every Radio Bearer (RB) setup request (including HO and RRC connection re-establishment), the eNodeB Radio Admission Control (RAC) entity checks the current eNodeB's ability to accept the request, considering factors such as:
  - maximum number of UEs and RBs,
  - number of RBs on GBR
  - hard capacity limit

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# Control Use of Resources
# Use of ARP and QCI During Initial Attach



UE    eNB    MME    SGW    PGW    HSS    PCRF    SPR

RACH Procedure

RRC Connection Setup Complete

**EstablishmentCause**

For Establishment Cause= highPriorityAccess, MME considers UE high priority

Attach Request

**EstablishmentCause**

Retrieves subscriber data incl. EPS-Subscribed-QoS profile [ARP, QCI]

Authentication Procedure          Authentication Procedure

Update Location Request

Update Location Answer

**ARP, QCI**

MME saves ARP/QCI in UE Context

Create Session Request

**ARP, QCI**

Create Session Request

**ARP, QCI**

Retrieves subscriber info used to evaluate request

IP-CAN Session Establishment

**ARP, QCI**    UDR

UDA

CC Answer

**ARP, QCI**

MME saves the ARP/ QCI received for each bearer in UE Context – **not allowed** to modify QCI

Create Session Response

**ARP, QCI**

PCRF - **allowed** to modify QCI, ARP

Instruct PGW to set up default bearer with ARP and QCI

eNB performs Connection Access Control

Create Session Response

**ARP, QCI**

Initial context setup request/ Attach Accept

**ARP, QCI**

MME sends the ARP/QCI values received in the Create Session Response

RRCConnectionReconfiguration/ Attach Accept

**QCI**

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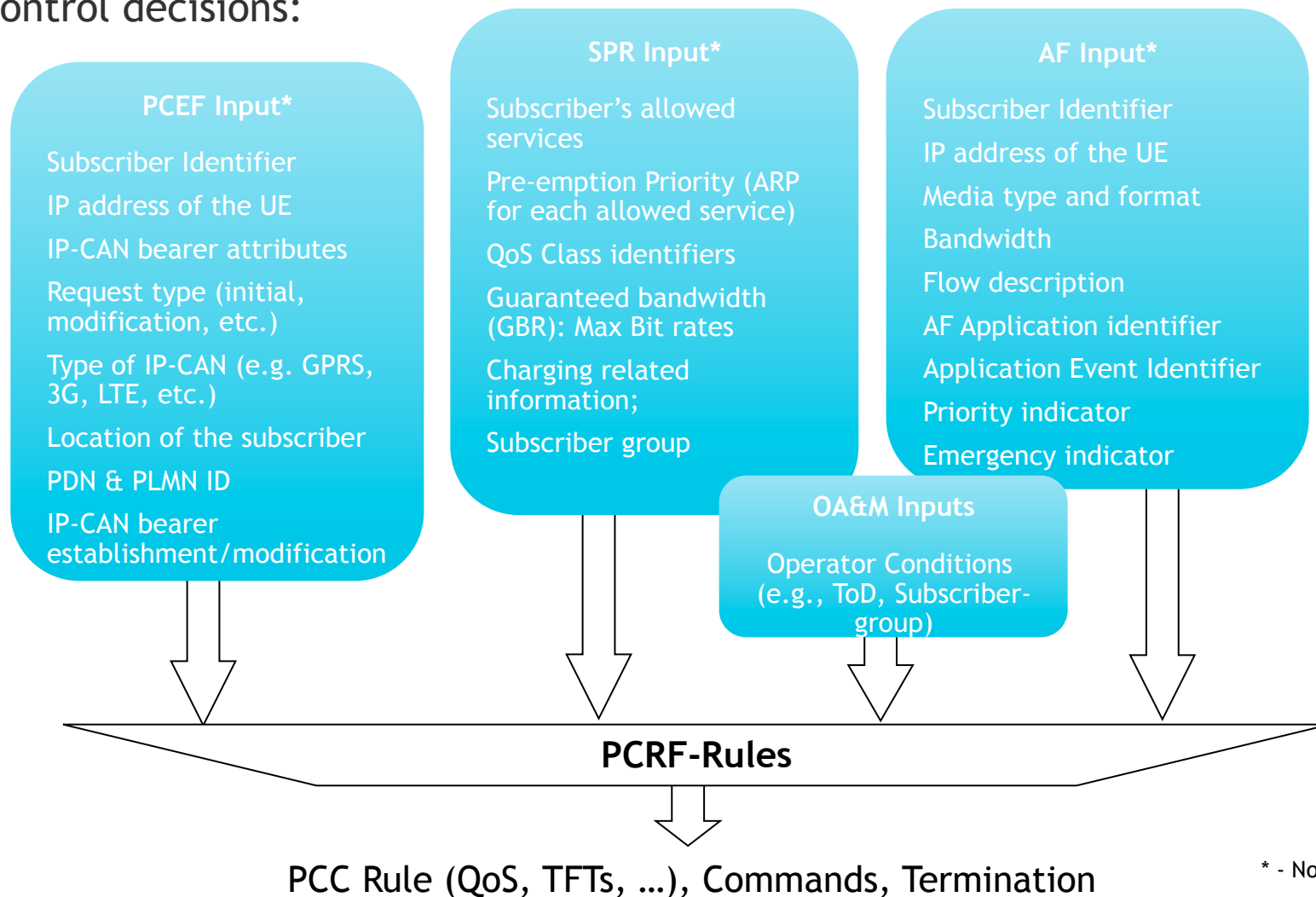
# Control Use of Resources
## PCRF Key Component to Policy Decisions

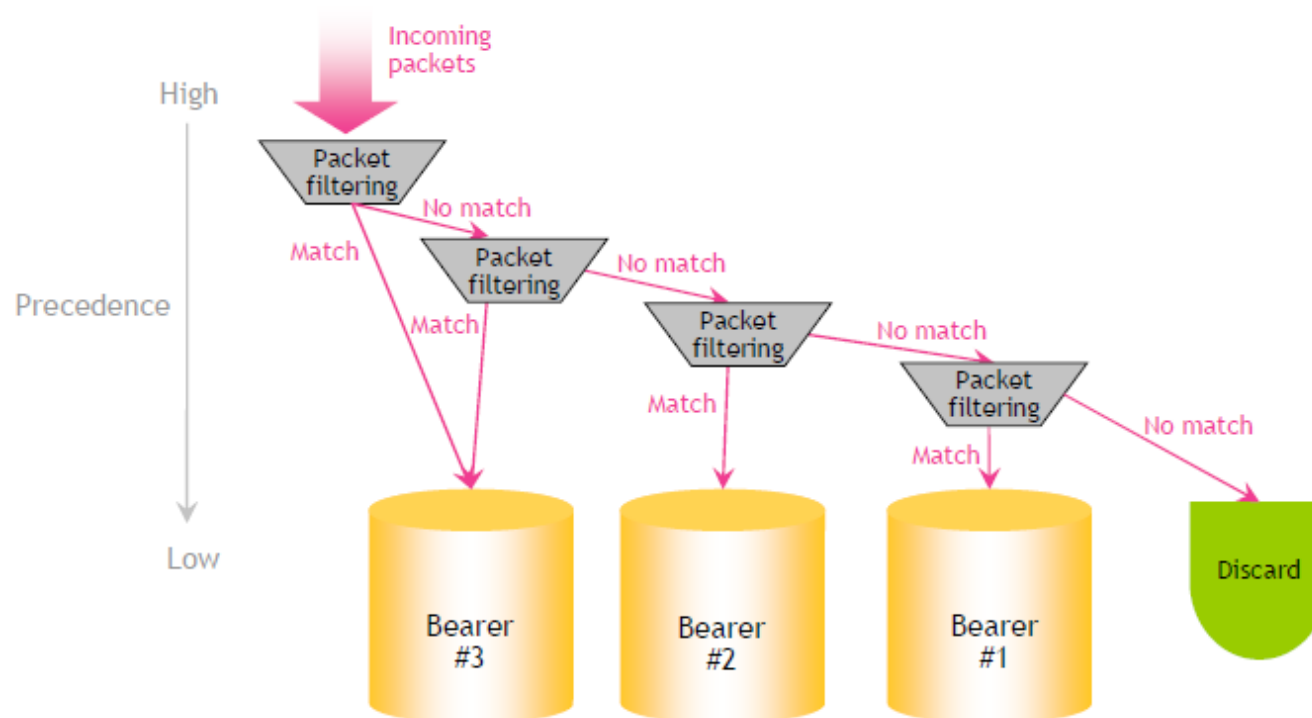The Rules Engine uses inputs from the PCEF, SPR, AF and O&M to make policy control decisions:

**PCEF Input***

Subscriber Identifier

IP address of the UE

IP-CAN bearer attributes

Request type (initial, modification, etc.)

Type of IP-CAN (e.g. GPRS, 3G, LTE, etc.)

Location of the subscriber

PDN & PLMN ID

IP-CAN bearer establishment/modification

**SPR Input***

Subscriber's allowed services

Pre-emption Priority (ARP for each allowed service)

QoS Class identifiers

Guaranteed bandwidth (GBR): Max Bit rates

Charging related information;

Subscriber group

**AF Input***

Subscriber Identifier

IP address of the UE

Media type and format

Bandwidth

Flow description

AF Application identifier

Application Event Identifier

Priority indicator

Emergency indicator

**OA&M Inputs**

Operator Conditions (e.g., ToD, Subscriber-group)

**PCRF-Rules**

PCC Rule (QoS, TFTs, ...), Commands, Termination

\* - Not an exhaustive list

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# Control Use of Resources
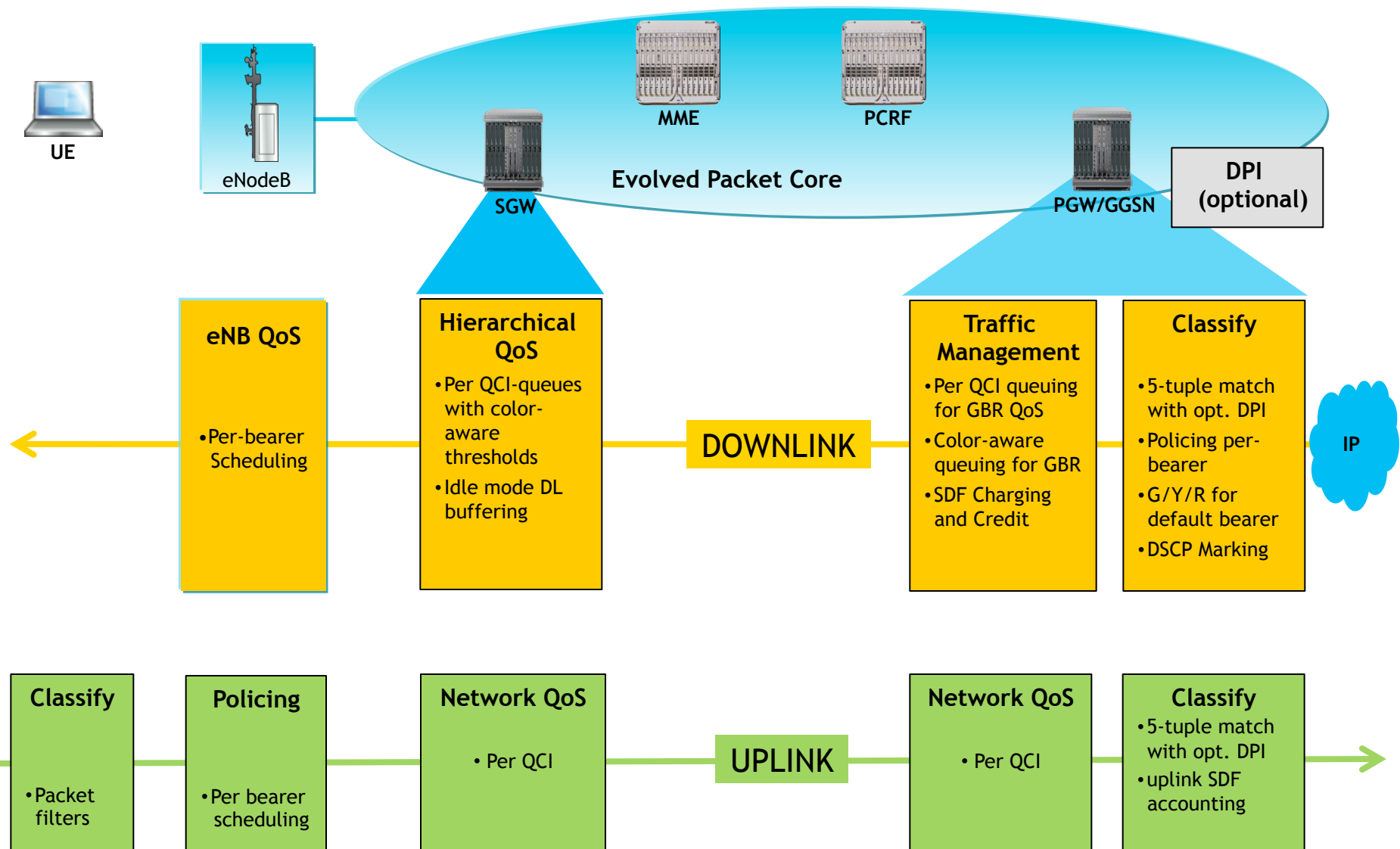## Traffic Flow Template – Details

List of packet filters, each containing the following information:

- Identifier of the packet filter
- Precedence of the packet filter
- Direction (UL and DL)
- Filter itself (e.g. pattern matching on IP 5-tuple)

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# Control Use of Resources
## End-To-End QoS View

**UE**

**eNodeB**

**MME**

**PCRF**

**Evolved Packet Core**

**SGW**

**PGW/GGSN**

**DPI (optional)**

**eNB QoS**

- Per-bearer Scheduling

**Hierarchical QoS**

- Per QCI-queues with color-aware thresholds
- Idle mode DL buffering

**DOWNLINK**

**Traffic Management**

- Per QCI queuing for GBR QoS
- Color-aware queuing for GBR
- SDF Charging and Credit

**Classify**

- 5-tuple match with opt. DPI
- Policing per-bearer
- G/Y/R for default bearer
- DSCP Marking

**IP**

**Classify**

- Packet filters

**Policing**

- Per bearer scheduling

**Network QoS**

- Per QCI

**UPLINK**

**Network QoS**

- Per QCI

**Classify**

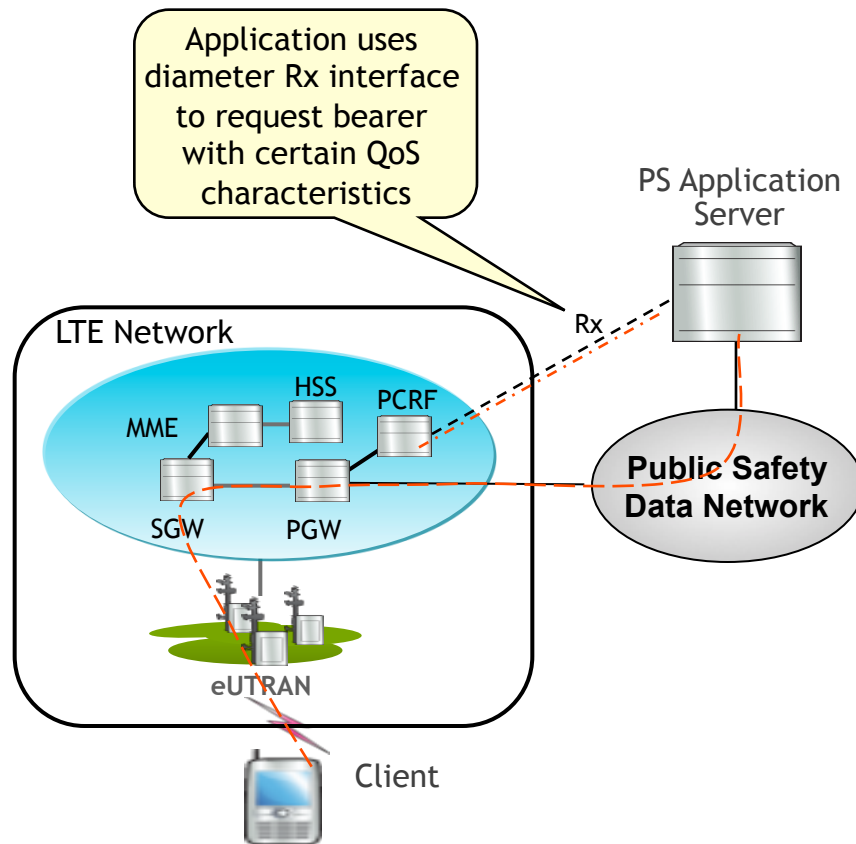- 5-tuple match with opt. DPI
- uplink SDF accounting

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## Application QoS Options

- The following options exist for providing QoS to applications in a deployment environment:
  - Use Rx interface from applications like voice or video application, acting as an application function to the PCRF
  - Use RESTful API
  - Preconfigured policy rules
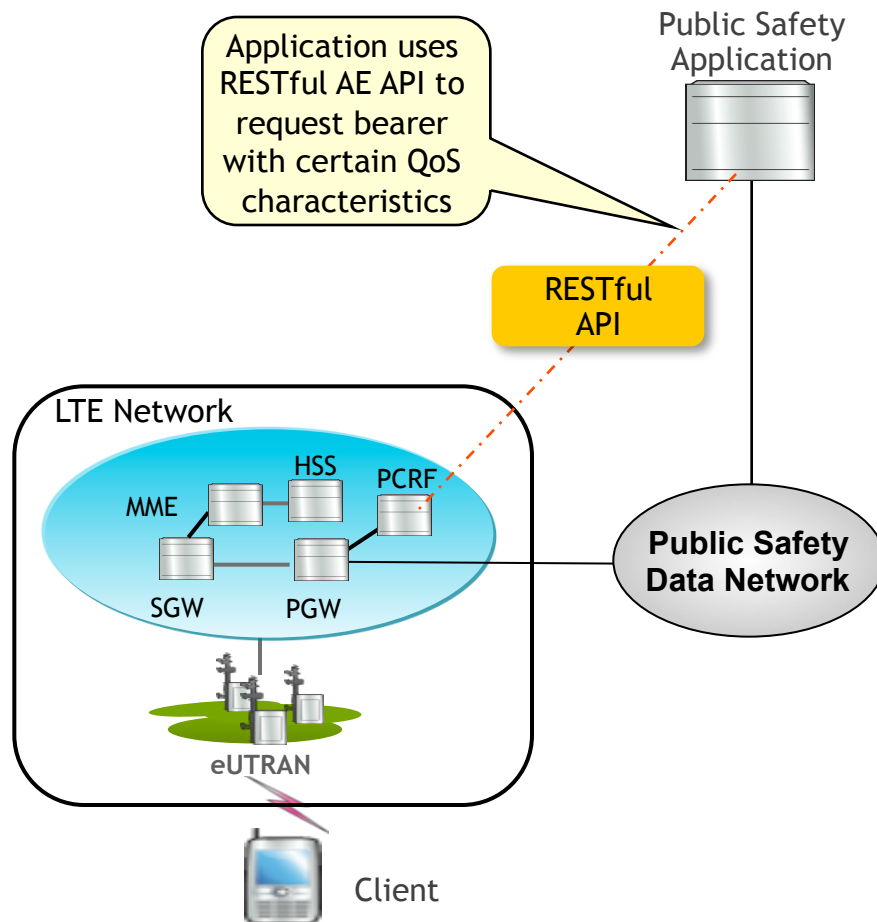  - UE software requests establishment of a dedicated bearer

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# Control Use of Air Resources

## Using Rx Interface

Application uses diameter Rx interface to request bearer with certain QoS characteristics

PS Application Server

LTE Network

Rx

HSS     PCRF

MME

SGW     PGW

Public Safety
Data Network

eUTRAN

Client

RX Interface defined in 3GPP 23.203 (stage 2) and 29.214 (stage 3)

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# Application QoS Options
## Using RESTful API

Application uses RESTful AE API to request bearer with certain QoS characteristics

Public Safety Application

RESTful API

LTE Network

HSS
MME
PCRF
SGW
PGW

eUTRAN

Public Safety Data Network

Client

GSMA OneAPI is standardizing RESTful API
- V1.0 available – covers:
    - SMS
    - MMS
    - Terminal location
    - …
- V2.0 targeted end 2010 – covers:
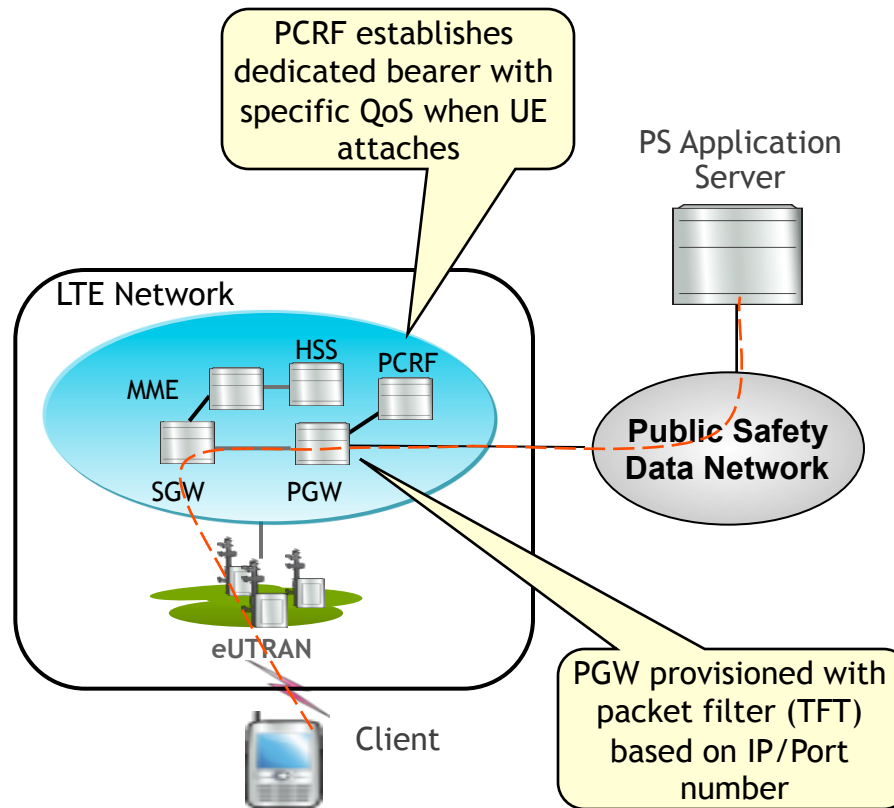    - Click to call
    - Call notification
    - Device capabilities
    - …
- V3.0 targeted 2011 – covers:
    - QoS for video streaming (QoS, ARP)
    - …

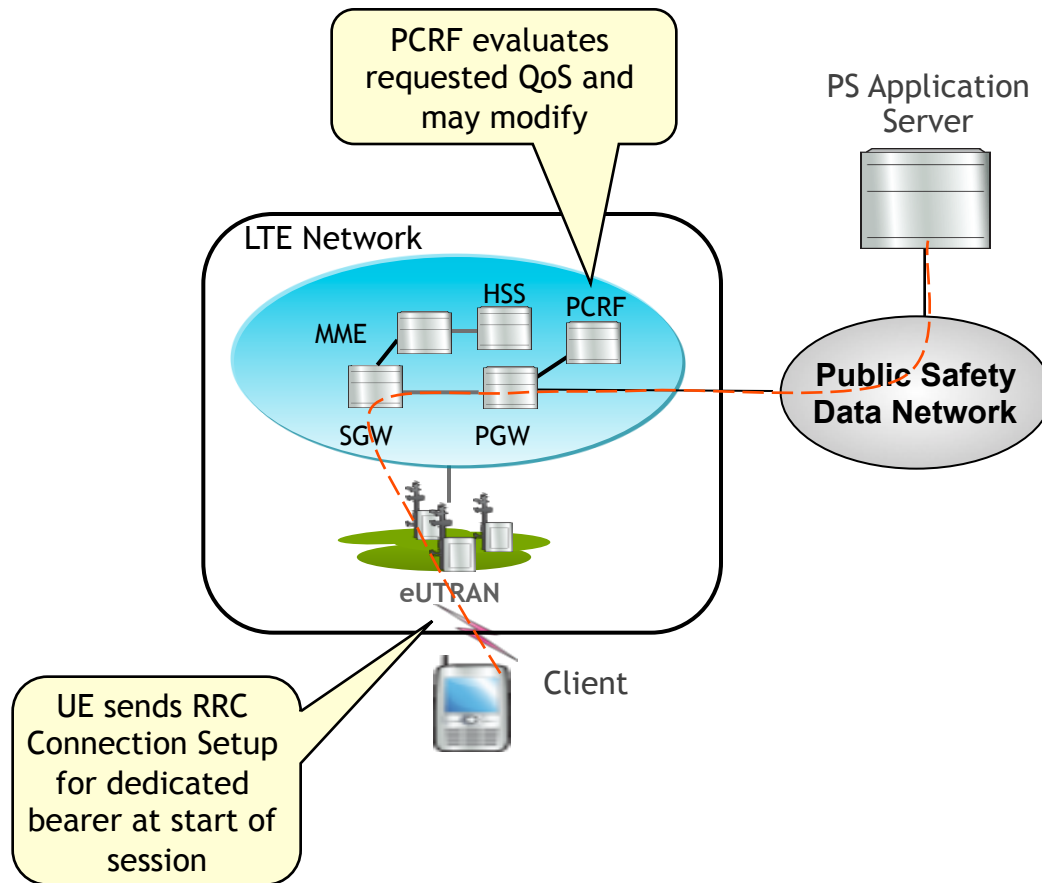Alcatel·Lucent

# Application QoS Options
# Preconfigured Policy Rules Using TFT Based on IP/Port Numbers

PCRF establishes dedicated bearer with specific QoS when UE attaches

PS Application Server

LTE Network

HSS

PCRF

MME

SGW    PGW

Public Safety
Data Network

eUTRAN

Client

PGW provisioned with packet filter (TFT) based on IP/Port number

TFT = Traffic Flow Template

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# Application QoS Options

## UE software requests establishment of a dedicated bearer

PCRF evaluates requested QoS and may modify

PS Application Server

LTE Network

HSS PCRF

MME

SGW PGW

Public Safety Data Network

eUTRAN

Client

UE sends RRC Connection Setup for dedicated bearer at start of session

Unknown whether there is a standardized API in the UE for this

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**3** Roaming/Handover Implications

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## Roaming and Handoff
## ARP and QoS

- Whenever a UE attaches to a roaming network the MME in the roaming network retrieves the ARP and QoS characteristics from the home HSS
  - When a bearer is requested the home policy is passed down from H-PCRF at HPLMN to V-PCRF at VPLMN via S9 interface for local breakout APNs
  - V-PCRF is allowed to modify ARP and QoS policy from H-PCRF based on visited QoS profile
  - Passed to PGW for policy enforcement function (PCEF)
  - Passed to eNB for admission control and upstream PCEF
- When UE is handed over from one LTE network to another, ARP and QCI are passed to MME in new network
  - Standards do not allow MME to modify QoS, but MME can reject request based on roaming agreements
  - Starting with 3GPP R10 MME is only allowed to modify ARP or APN-AMBR
- AF interfaces to PCRF in associated network to request dedicated bearer QoS
  - PCRF performs policy decision function (PDF) to decide the policy based on Subscriber Policy Repository (SPR) data and AF information
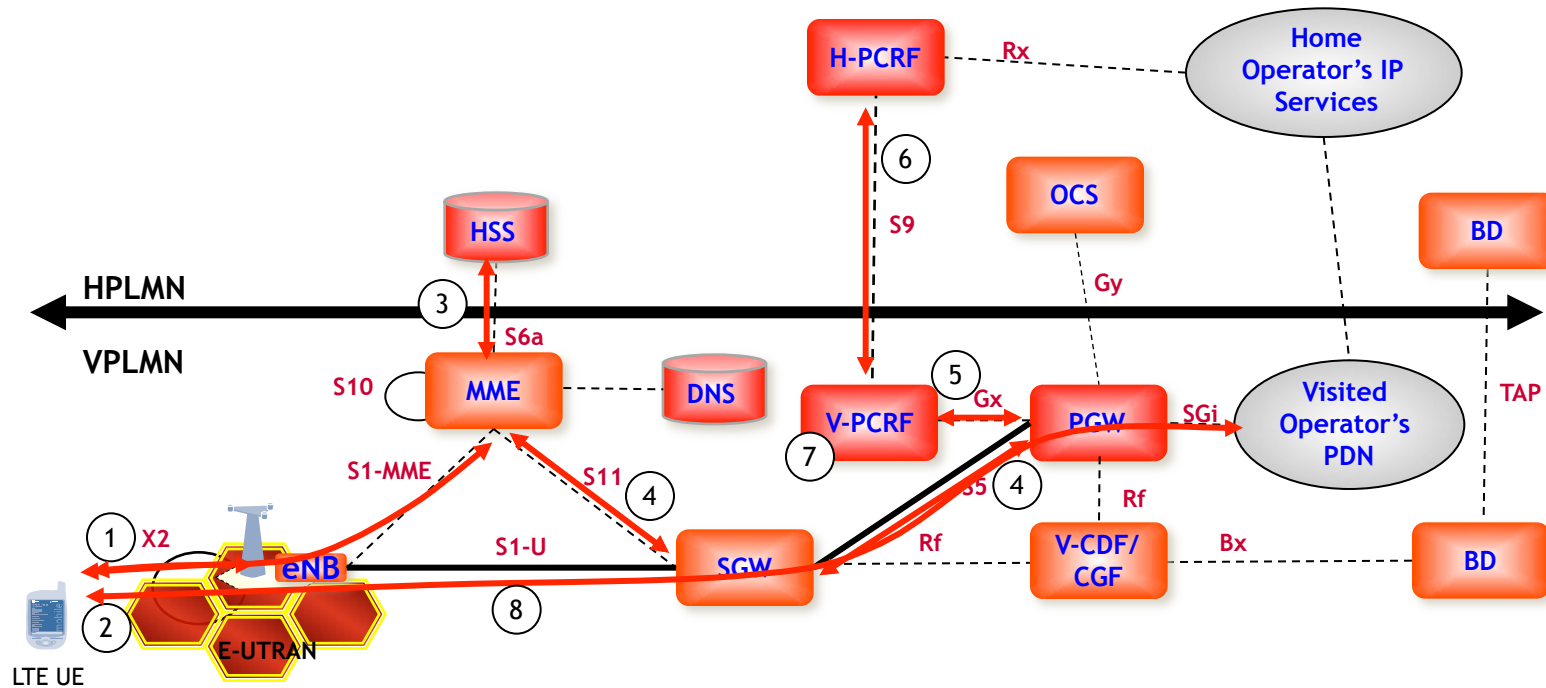
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# UE Attach for Home Routed Model
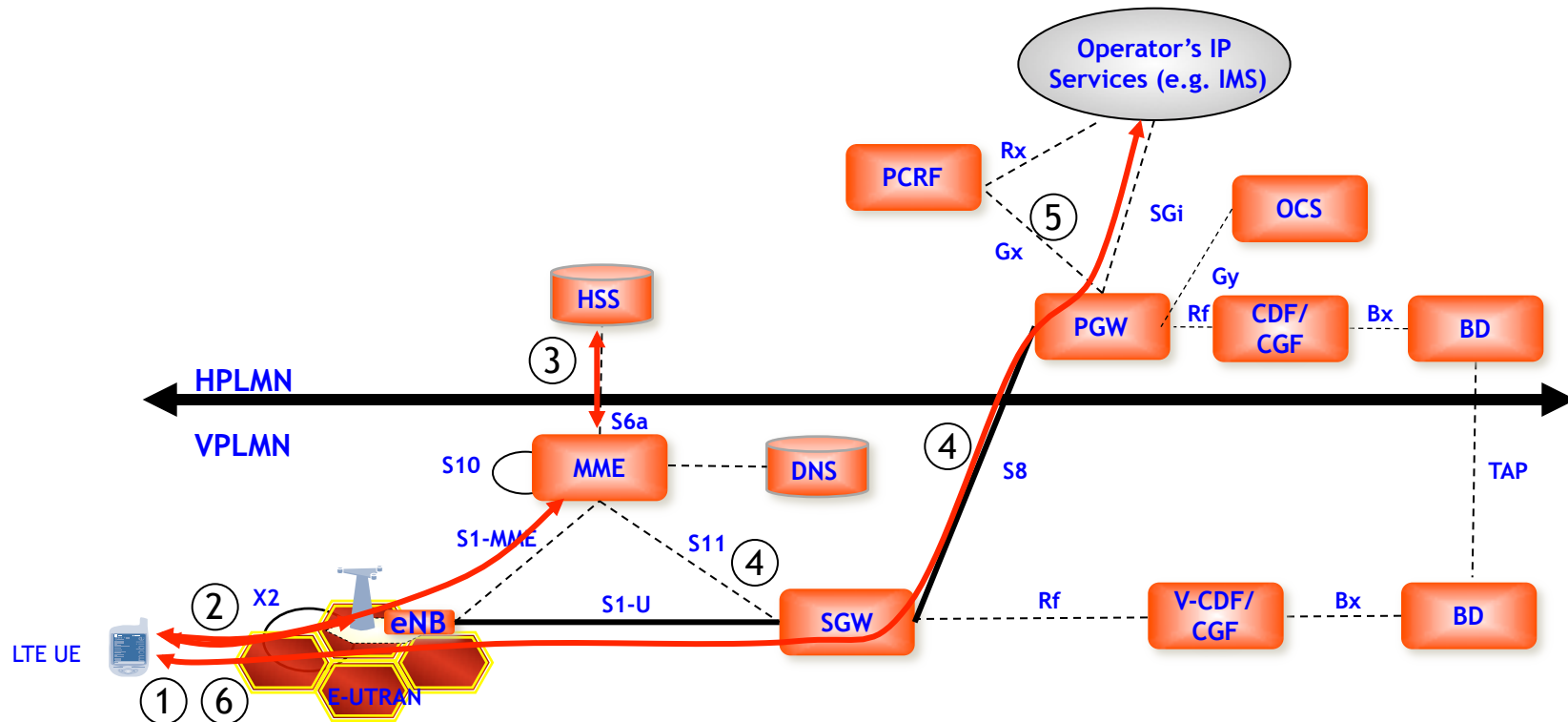


① Establish RRC connection

② MME initiates authentication & security mode with HSS and UE

③ Subscriber Data Query – HSS selected based on PLMN id (see next slide)

④ MME selects SGW & PDN GW and establish PDN connection based on APN data in HSS

⑤ IP CAN session establishment with QoS policy Query

⑥ Activate the default bearer

Visiting network has no control over QoS (strictly controlled by home network)

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# UE Attach for Local Breakout Model

Animated



1. Establish RRC connection
2. MME initiates authentication & security mode with HSS and UE
3. Subscriber Data Query – HSS selected based on PLMN id
4. MME selects SGW & PDN GW and establish PDN connection based on APN data in HSS

5. IP CAN session establishment with QoS policy Query
6. PCRF sends request to H-PCRF based on PDN id
7. V-PCRF may modify response from H-PCRF
8. Activate the default bearer

**Visiting network can modify priority and/or QoS requested by home network**

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# 4

# VPN Implications

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# Discussion Topics

- Impact of VPN use for other than data-only applications

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# Backup

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## LTE Acronyms - 1

- AC — Access Class
- AF — Application Function
- AMBR — Aggregate Maximum Bit Rate
- API — Application Programming Interface
- APN — Access Point Name
- ARP — Allocation and Retention Priority
- BCCH — Broadcast Control Channel
- BCH — Broadcast Channel
- CAN — Connectivity Access Network
- CCA — Credit Control Answer
- CCCH — Common Control CHannel
- CCR — Credit Control Request
- CN — Core Network
- CTCH — Common Traffic Channel
- DCCH — Dedicated Control Channel
- DL-SCH — Downlink Shared Channel
- DL TFT — Downlink Traffic Flow Template
- DPI — Deep Packet Inspection
- DSCP — Differentiated Services Code Point
- EIR — Equipment Identity Register
- eNB — Evolved Node B
- EPC — Evolved Packet Core
- EPS — Evolved Packet System or Service
- e-UTRAN — Evolved UMTS Terrestrial RAN
- GBR — Guaranteed Bit Rate
- GTP — GPRS Tunneling Protocol
- GW — Gateway
- H-PCRF — Home-PCRF
- HSS — Home Subscriber System
- IP-CAN — IP Connectivity Access Network
- LTE — Long Term Evolution

- MBR — Maximum Bit Rate
- MIB — Master Information Block
- MIMO — Multiple Input Multiple Output
- MME — Mobility Management Entity
- MTCH — Multicast Traffic Channel
- NACC — Network Assisted Cell Change
- NAS — Network Access Server & Non-Access Stratum
- NGN GETS — NGN Government Emergency Telecommunications Service
- OA&M — Operations, Administration & Maintenance
- PCC — Policy and Charging Control
- PCEF — Policy and Charging Enforcement Function
- PCRF — Policy Charging and Rules Function
- PGW — PDN Gateway
- QCI — QoS Class Identifier
- QoS — Quality of Service
- RAC — Radio Access Control
- RB — Radio Bearer
- RRC — Radio Resource Control
- SDF — Service Data Flow
- SGW — Serving GW
- SIB1 — System Information Block 1
- SIB2 — System Information Block 2
- SPR — Subscriber Priority Repository
- TFT — Traffic Flow Template
- UE — User Equipment
- UL — Uplink
- USIM
- V-PCRF — Visiting PCRF
- VPN — Virtual Private Network

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# Control Use of Resources
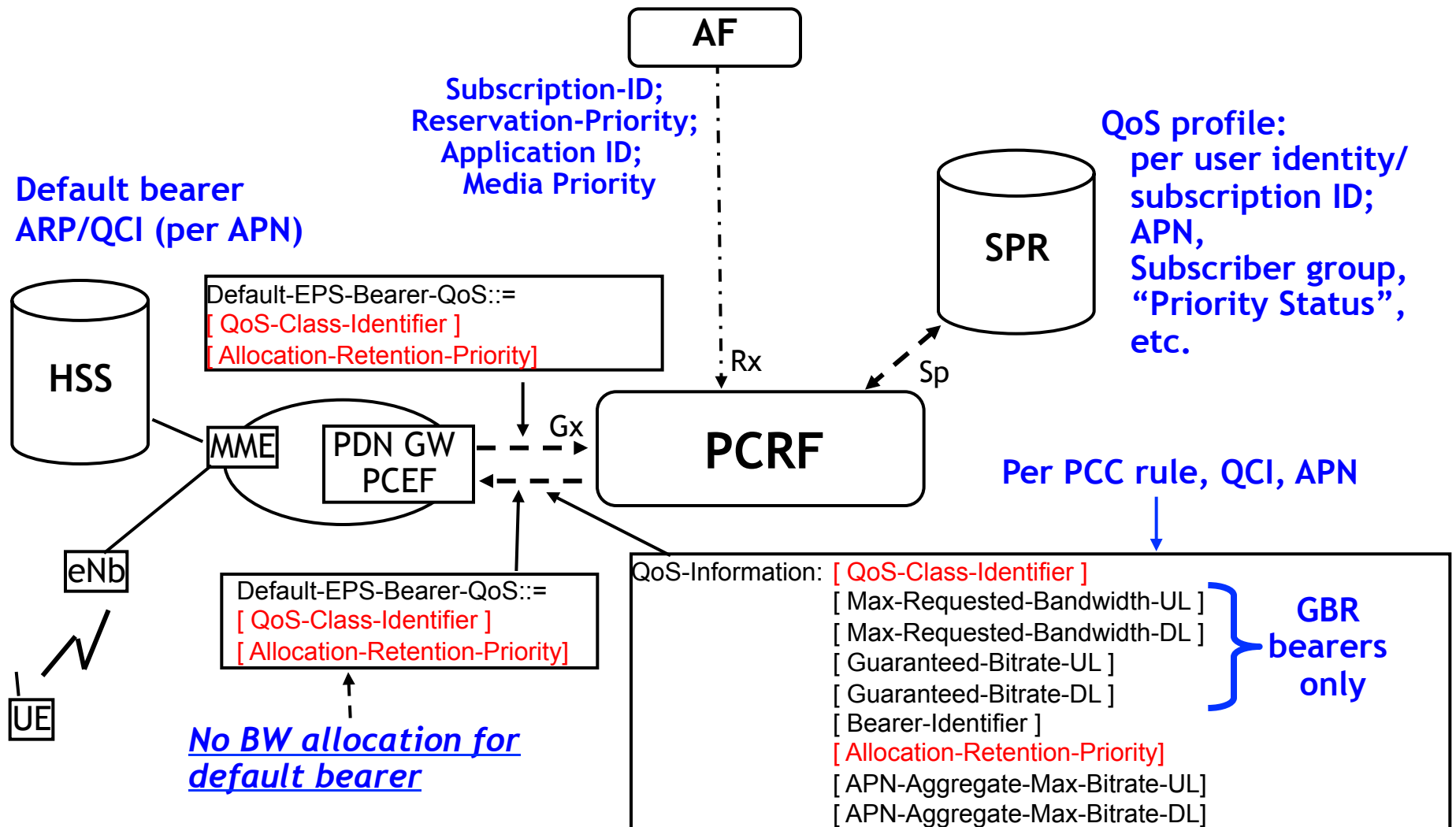## Standardized QCI Characteristics

2G

- Conversational
- Streaming

3G

- Interactive
- Background
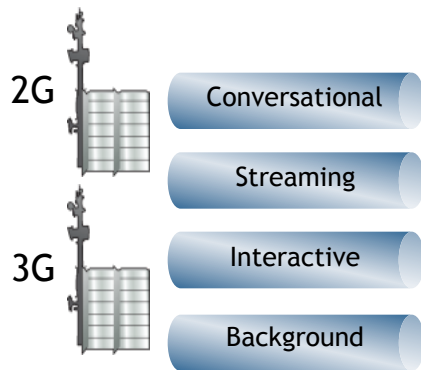
From: 4 classes in UMTS and CDMA
To:   **9 classes (QCI) in LTE**

SDF priorities

Maximum delay
between PCEF and UE

| QCI | Resource Type | Priority | Packet Delay Budget | Packet Error Loss Rate | Example Services |
|-----|---------------|----------|---------------------|------------------------|------------------|
| 1 | **GBR** | 2 | 100 ms | 10-2 | Conversational voice |
| 2 | **GBR** | 4 | 150 ms | 10-3 | Conversational video (live streaming) |
| 3 | **GBR** | 3 | 50 ms | 10-3 | **Robotics** |
| 4 | **GBR** | 5 | 300 ms | 10-6 | Non-conversational video (buffered streaming) |
| 5 | **Non-GBR** | 1 | 100 ms | 10-6 | IMS signaling |
| 6 | **Non-GBR** | 6 | 300 ms | 10-6 | Video (buffered streaming) TCP-based (e.g., www, email, chat, ftp, p2p file sharing, progressive video, etc.) |
| 7 | **Non-GBR** | 7 | 100 ms | 10-3 | Voice, video (live streaming), interactive gaming |
| 8 | **Non-GBR** | 8 | 300 ms | 10-6 | "Premium bearer" for video (buffered streaming) TCP-based (e.g., www, email, chat, ftp, p2p file sharing, progressive video, etc.) for premium subscribers |
| 9 | **Non-GBR** | 9 | | | "Default bearer" for video TCP-based services, etc. for non-privileged subscribers |

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# Control Use of Resources
## Determination of ARP for EPS bearer – PCRF "Output"

**AF**

Subscription-ID;
Reservation-Priority;
Application ID;
Media Priority

QoS profile:
per user identity/
subscription ID;
APN,
Subscriber group,
"Priority Status",
etc.

**SPR**

**Default bearer
ARP/QCI (per APN)**

Default-EPS-Bearer-QoS::=
[ QoS-Class-Identifier ]
[ Allocation-Retention-Priority]

Rx

Sp

**HSS**

Gx

**PCRF**

MME

PDN GW
PCEF

eNb

**Per PCC rule, QCI, APN**

Default-EPS-Bearer-QoS::=
[ QoS-Class-Identifier ]
[ Allocation-Retention-Priority]

UE

***No BW allocation for
default bearer***

QoS-Information: [ QoS-Class-Identifier ]
[ Max-Requested-Bandwidth-UL ]
[ Max-Requested-Bandwidth-DL ]
[ Guaranteed-Bitrate-UL ]
[ Guaranteed-Bitrate-DL ]
[ Bearer-Identifier ]
[ Allocation-Retention-Priority]
[ APN-Aggregate-Max-Bitrate-UL]
[ APN-Aggregate-Max-Bitrate-DL]

**GBR
bearers
only**

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# Control Use of Air Resources
# Rx Interface Flow



**GW**    **PCRF**    **AF**    **SPR**

{Subscription-ID;IP@;
Media Type/Media
Priority; Reservation-
priority; Application-ID

1.  Trigger

2.  Define service
    information

GET SUB-Profile
{Subscription-ID;IP@; }

3.  Diameter AAR

4.  Store Service
    Information

*If the PCRF
needs
subscription
–related
information
and does
not have it*

5.  Profile Request

6.  Profile Response

7.  Identify affected IP CAN
    session(s)

8.  Diameter AAA

**Legend:**

—————————▶  *Mandatory*

- - - - - - -▶  *Conditional*

9.  Establish Dedicated bearer

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# Application QoS Options
# Call Flow for UE Initiated Service Request

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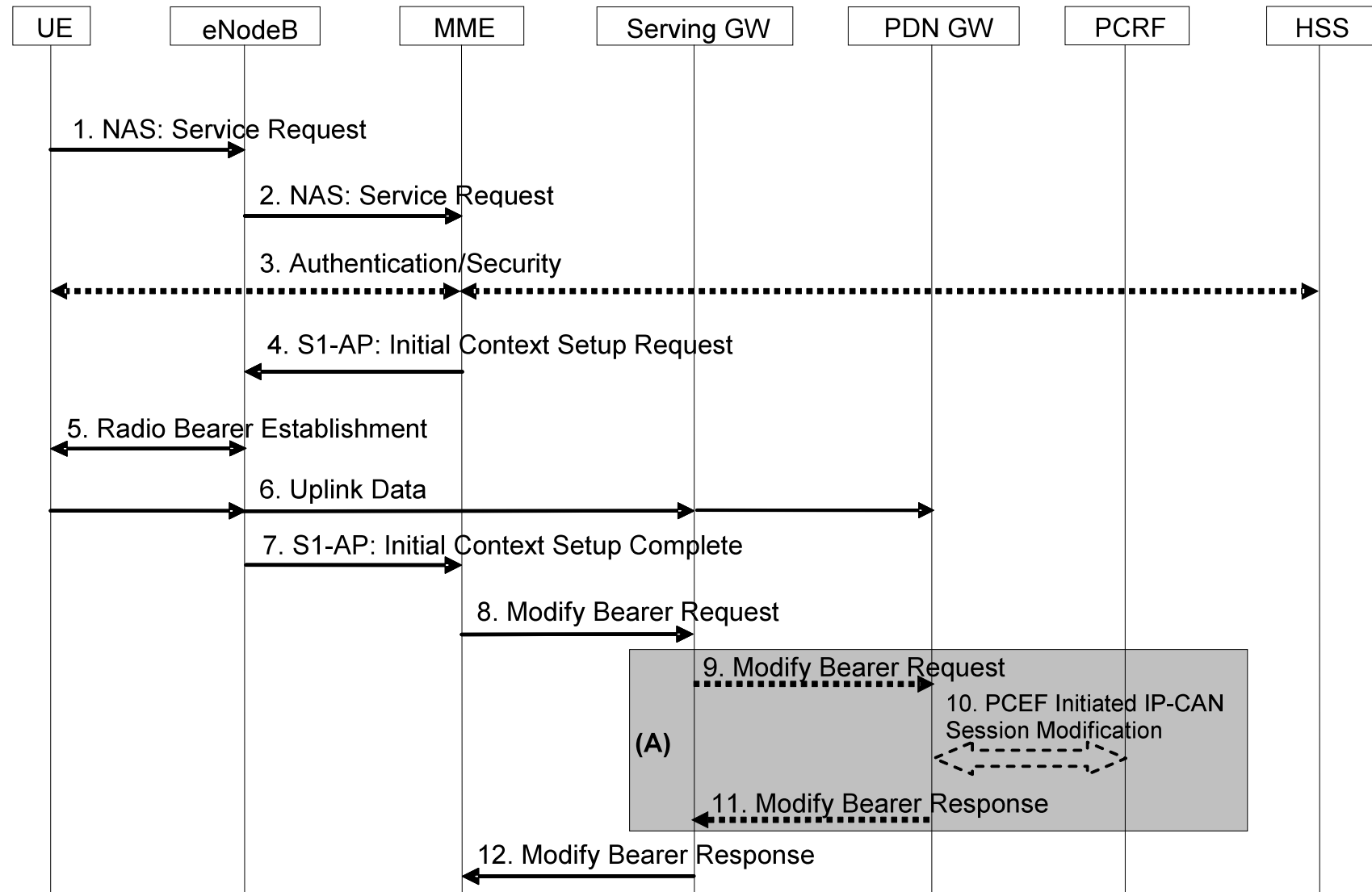
# Admission Control
# Use of ARP During HO

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