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
1 Control Access to Air Interface
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, ..)
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
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

<table>
<thead>
<tr>
<th>Establishment causes available i.e.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
</tr>
<tr>
<td>High priority access</td>
</tr>
<tr>
<td>Mobile terminating access</td>
</tr>
<tr>
<td>Mobile originating access</td>
</tr>
<tr>
<td>Mobile originating signaling</td>
</tr>
<tr>
<td>Mobile originated data</td>
</tr>
</tbody>
</table>

**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)

**Access Control:**
Access Class Barring

**CAC for SRB1 & SRB2**
Control Use of Resources
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
### Control Use of Resources

#### EPS Bearer Management - Two Types of Bearers

<table>
<thead>
<tr>
<th>Guaranteed Bit Rate (GBR)</th>
<th>Non-Guaranteed Bit Rate (Non-GBR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified Guaranteed Bit Rate (GBR) and Maximum Bit Rate (MBR)</td>
<td>May have a Maximum Bit Rate (MBR)</td>
</tr>
<tr>
<td>▪ Note currently MBR=GBR (3GPP)</td>
<td></td>
</tr>
<tr>
<td>Has associated ARP and QCI</td>
<td>Has associated ARP and QCI</td>
</tr>
<tr>
<td>Service will not experience congestion-related packet loss (provided that the user traffic is compliant to the agreed GBR QoS parameters)</td>
<td>Service must be prepared to experience congestion-related packet loss</td>
</tr>
<tr>
<td>Established on demand because it allocates transmission resources by reserving them during the admission control function</td>
<td>Can remain established for long periods of time because it does not reserve transmission resources</td>
</tr>
<tr>
<td>Precedence of service blocking over service dropping in congestion situation</td>
<td>Precedence of service dropping over service blocking in congestion situation</td>
</tr>
<tr>
<td>Inactivity timers are used to control air interface and S1 interface to free up resources</td>
<td>Stay up (no reserved resources)</td>
</tr>
</tbody>
</table>
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)**
  - 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 non-GBR bearers per terminal/Access Point Name (APN)**

*EPS or Evolved Packet System is the eUTRAN + EPC (radio + core) combination
Traffic Filter Templates at both UE and PGW are responsible for distributing SDFs between EPS bearers
Control Use of Resources
Mapping applications to LTE QoS Classes (QCIs): The 3GPP view

- 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.
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
Control Use of Resources
Use of ARP and QCI During Initial Attach

UE
RACH Procedure

eNB
RRC Connection Setup Complete
EstablishmentCause

MME
Attach Request
EstablishmentCause
Authentication Procedure
Update Location Request
Update Location Answer
ARP, QCI
Create Session Request
Create Session Response
Initial context setup request/
Attach Accept
RRConnectionReconfiguration/
Attach Accept
QCI

SGW

PGW
Instruct PGW to set up default bearer with ARP and QCI

HSS
UAR

PCRF
UDR

SPR
UDA

For Establishment Cause= highPriorityAccess, MME considers UE high priority

MME saves ARP/QCI in UE Context

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

eNB performs Connection Access Control

Insert subscriber info used to evaluate request

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

Retrieves subscriber info used to evaluate request

Instruct PCRF to consider UE high priority

Authentication Procedure
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)

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PCRF-Rules

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

* - Not an exhaustive list
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)
Control Use of Resources
End-To-End QoS View

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

**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

**Network QoS**
- Per QCI

**Classify**
- Packet filters

**Policing**
- Per bearer scheduling

**Network QoS**
- Per QCI

**Classify**
- 5-tuple match with opt. DPI
- Uplink SDF accounting

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16 | Public Safety in LTE | September 2010
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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
Control Use of Air Resources
Using Rx Interface

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

RX Interface defined in 3GPP 23.203 (stage 2) and 29.214 (stage 3)
Application QoS Options
Using RESTful API

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)
  - ...

Application uses RESTful AE API to request bearer with certain QoS characteristics
Application QoS Options
Preconfigured Policy Rules Using TFT Based on IP/Port Numbers

PCRF establishes dedicated bearer with specific QoS when UE attaches

TFT = Traffic Flow Template
Application QoS Options
UE software requests establishment of a dedicated bearer

Unknown whether there is a standardized API in the UE for this
Roaming/Handover Implications
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
Roaming and Handoff

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)

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

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
Roaming and Handoff

UE Attach for Local Breakout 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
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
4 VPN Implications
Discussion Topics

- Impact of VPN use for other than data-only applications
### LTE Acronyms - 1

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Access Class</td>
</tr>
<tr>
<td>AF</td>
<td>Application Function</td>
</tr>
<tr>
<td>AMBR</td>
<td>Aggregate Maximum Bit Rate</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>APN</td>
<td>Access Point Name</td>
</tr>
<tr>
<td>ARP</td>
<td>Allocation and Retention Priority</td>
</tr>
<tr>
<td>BCCH</td>
<td>Broadcast Control Channel</td>
</tr>
<tr>
<td>BCH</td>
<td>Broadcast Channel</td>
</tr>
<tr>
<td>CAN</td>
<td>Connectivity Access Network</td>
</tr>
<tr>
<td>CCA</td>
<td>Credit Control Answer</td>
</tr>
<tr>
<td>CCCH</td>
<td>Common Control Channel</td>
</tr>
<tr>
<td>CCR</td>
<td>Credit Control Request</td>
</tr>
<tr>
<td>CN</td>
<td>Core Network</td>
</tr>
<tr>
<td>CTCH</td>
<td>Common Traffic Channel</td>
</tr>
<tr>
<td>DCCH</td>
<td>Dedicated Control Channel</td>
</tr>
<tr>
<td>DL-SCH</td>
<td>Downlink Shared Channel</td>
</tr>
<tr>
<td>DL TFT</td>
<td>Downlink Traffic Flow Template</td>
</tr>
<tr>
<td>DPI</td>
<td>Deep Packet Inspection</td>
</tr>
<tr>
<td>DSCP</td>
<td>Differentiated Services Code Point</td>
</tr>
<tr>
<td>EIR</td>
<td>Equipment Identity Register</td>
</tr>
<tr>
<td>eNB</td>
<td>Evolved Node B</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>EPS</td>
<td>Evolved Packet System or Service</td>
</tr>
<tr>
<td>e-UTRAN</td>
<td>Evolved UMTS Terrestrial RAN</td>
</tr>
<tr>
<td>GBR</td>
<td>Guaranteed Bit Rate</td>
</tr>
<tr>
<td>GTP</td>
<td>GPRS Tunneling Protocol</td>
</tr>
<tr>
<td>GW</td>
<td>Gateway</td>
</tr>
<tr>
<td>H-PCRF</td>
<td>Home-PCRF</td>
</tr>
<tr>
<td>HSS</td>
<td>Home Subscriber System</td>
</tr>
<tr>
<td>IP-CAN</td>
<td>IP Connectivity Access Network</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MBR</td>
<td>Maximum Bit Rate</td>
</tr>
<tr>
<td>MIB</td>
<td>Master Information Block</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>MME</td>
<td>Mobility Management Entity</td>
</tr>
<tr>
<td>MTCH</td>
<td>Multicast Traffic Channel</td>
</tr>
<tr>
<td>NACC</td>
<td>Network Assisted Cell Change</td>
</tr>
<tr>
<td>NAS</td>
<td>Network Access Server &amp; Non-Access Stratum</td>
</tr>
<tr>
<td>NGN GETS</td>
<td>NGN Government Emergency Telecommunications Service</td>
</tr>
<tr>
<td>OA&amp;M</td>
<td>Operations, Administration &amp; Maintenance</td>
</tr>
<tr>
<td>PCC</td>
<td>Policy and Charging Control</td>
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<tr>
<td>PCEF</td>
<td>Policy and Charging Enforcement Function</td>
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<tr>
<td>PCRF</td>
<td>Policy Charging and Rules Function</td>
</tr>
<tr>
<td>PGW</td>
<td>PDN Gateway</td>
</tr>
<tr>
<td>QCI</td>
<td>QoS Class Identifier</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RAC</td>
<td>Radio Access Control</td>
</tr>
<tr>
<td>RB</td>
<td>Radio Bearer</td>
</tr>
<tr>
<td>RRC</td>
<td>Radio Resource Control</td>
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<tr>
<td>SDF</td>
<td>Service Data Flow</td>
</tr>
<tr>
<td>SGW</td>
<td>Serving GW</td>
</tr>
<tr>
<td>SIB1</td>
<td>System Information Block 1</td>
</tr>
<tr>
<td>SIB2</td>
<td>System Information Block 2</td>
</tr>
<tr>
<td>SPR</td>
<td>Subscriber Priority Repository</td>
</tr>
<tr>
<td>TFT</td>
<td>Traffic Flow Template</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>UL</td>
<td>Uplink</td>
</tr>
<tr>
<td>USIM</td>
<td></td>
</tr>
<tr>
<td>V-PCRF</td>
<td>Visiting PCRF</td>
</tr>
<tr>
<td>VPN</td>
<td>Virtual Private Network</td>
</tr>
</tbody>
</table>
## Control Use of Resources
### Standardized QCI Characteristics

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

From: 4 classes in UMTS and CDMA
To: 9 classes (QCI) in LTE
Control Use of Resources

Determination of ARP for EPS bearer - PCRF “Output”

Default bearer
ARP/QCI (per APN)

HSS

MME

PDN GW

PCEF

AF

SPR

PCRF

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

Per PCC rule, QCI, APN

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]

No BW allocation for default bearer
Control Use of Air Resources
Rx Interface Flow

1. Trigger
2. Define service information
3. Diameter AAR
4. Store Service Information
5. Profile Request
6. Profile Response
7. Identify affected IP CAN session(s)
8. Diameter AAA
9. Establish Dedicated bearer

Legend:
- Mandatory
- Conditional

GET SUB-Profile {Subscription-ID;IP@; }
Application QoS Options

Call Flow for UE Initiated Service Request

1. NAS: Service Request
2. NAS: Service Request
3. Authentication/Security
4. S1-AP: Initial Context Setup Request
5. Radio Bearer Establishment
6. Uplink Data
7. S1-AP: Initial Context Setup Complete
8. Modify Bearer Request
9. Modify Bearer Request
10. PCEF Initiated IP-CAN Session Modification
11. Modify Bearer Response
12. Modify Bearer Response
Admission Control
Use of ARP During HO

1. **measurementReport**
   - meassId
   - measResultServing
   - neighbouringMeasResults

2. **Handover decision**

3. **Setup of UE associated resources in the target cell**

4. **RRCConnectionReconfiguration**
   - MeasurementConfiguration
   - MobilityControlInformation
   - RadioResourceConfigDedicated
   - UE-RelatedInformation

5. **Switch DL to target cell**
   - Start receiving UL in target cell

6. **Start transmitting DL in target cell**

7. **Detach from old cell and synchronize to new cell**

8. **Release UE associated resources in the source cell**

9. **CAC for HO - CMC**

10. **UE**
    - **Source/Target ENB**
    - **MME/SGW**