White Paper

radisys

Protocol Signaling Procedures in LTE

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Overview

The exploding growth of the internet and associated services has fueled the need for more and more bandwidth. Handheld devices are growing exponentially and thus the need for the services on the move has increased tremendously. Current 3G technology is able to cope with the demand to some extent but unable to satisfy the needs completely.

Long Term Evolution (LTE) promises higher data rates, 100Mbps in the downlink and 50Mbps in the uplink in LTE's first phase, and will reduce the data plane latency and supports interoperability with other technologies such as GSM, GPRS and UMTS. Plus, LTE has support for scalable bandwidth, from 1.25MHz to 20MHz. All these features make LTE a very attractive technology for operators as well as the subscribers.

In this paper we briefly touch upon the procedures executed by LTE user equipment (UE) and the various LTE network elements in order to provide the services requested by the UE.

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Network Architecture

In Figure 1, the architecture of the LTE network is given with the various interfaces between the network elements; GERAN and UTRAN networks are shown for completeness.

The functions of the various network elements are:

- *eNodeB:* Radio Resource Management functions, IP header compression, encryption of user data streams, selection of an MME, routing of user plane data to S-GW, scheduling and transmission of paging message.
- *MME:* NAS signaling (eMM, eSM) and security, AS security, tracking area list management, PDN GW and S-GW selection, handovers (intra- and inter-LTE), authentication, bearer management.
- *S-GW:* The local mobility anchor point for inter-eNodeB handover; downlink packet buffering and initiation of network-triggered service requests, lawful interception, accounting on user and QCI granularity, UL/DL charging per UE.
- *P-GW:* UE IP address allocation, packet filtering and PDN connectivity, UL and DL service-level charging, gating and rate enforcement.

Figure 2 shows the protocol stacks at various LTE network elements.

Bearers in LTE

In LTE, end-to-end bearers are realized by the EPS bearers, which are a collection of radio, S1 and S5/S8 bearers. An EPS bearer identity uniquely identifies an EPS bearer for one UE accessing via E-UTRAN. The EPS Bearer Identity is allocated by the MME and is the one that carries the information; usually it carries the user data.

There are three kinds of bearers in LTE: Radio Bearers, S1 Bearers and EPS Bearers as depicted in the Figure 3. In the UE, the uplink TFT maps a traffic flow aggregate to an EPS bearer in the uplink direction and in PGW the downlink TFT maps a traffic flow aggregate to an EPS bearer in the downlink direction. There is much more complexity than what is summarized here, but for brevity's sake it suffices to say that traffic off-loaders

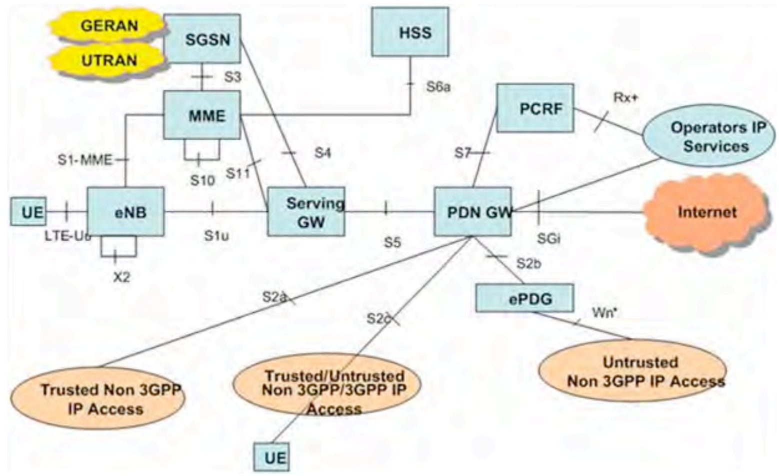

Figure 1. *LTE Network Architecture*

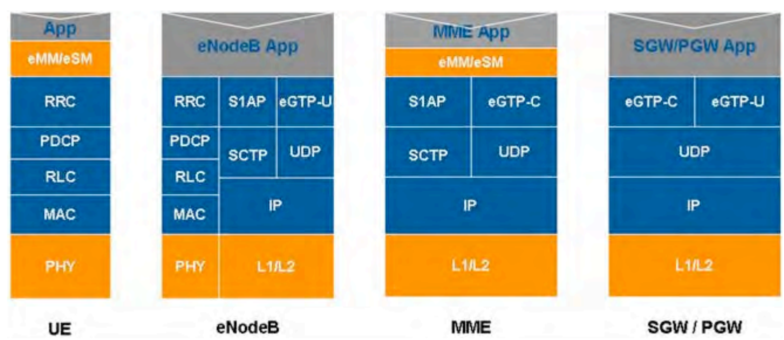

Figure 2. *LTE Control/User Plane Protocol Stacks*

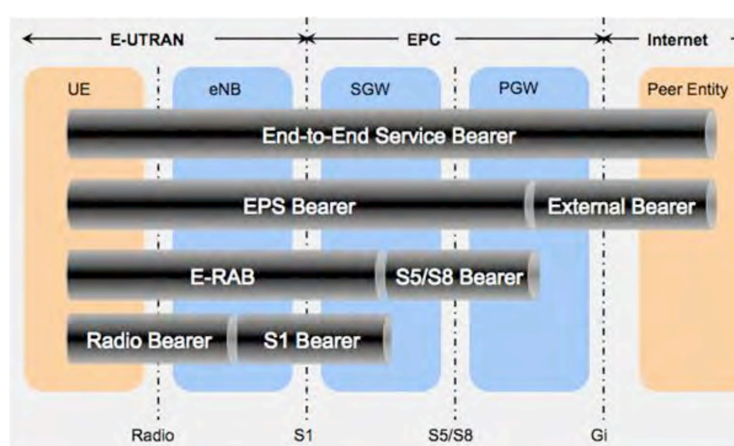

Figure 3. *LTE Bearer Architecture*

classify traffic streams using DPI and then, based on the operator's policies, offload part of the traffic directly onto the Internet while sending the remaining traffic to the core network. Traffic off-loaders typically will be deployed as "bump-in-the-wire" boxes between the radio access network (RAN) and the core network (CN); in the future, some Radio Network Controllers (RNCs) might include this functionality inside the box.

- *Radio Bearer:* A radio bearer transports the packets of an EPS bearer between the UE and an eNodeB.
- *S1 Bearer:* An S1 bearer transports the packets of an EPS bearer between an eNodeB and a S-GW.
- *S5/S8 Bearer:* An S5/S8 bearer transports the packets of an EPS bearer between the S-GW and the PDN GW.

There is a one-to-one mapping between radio, S1 and S5/S8 bearers; this end-to-end EPS bearer realizes the negotiated QoS for the service.

System Information Broadcasting

To get service from the network, a UE has to select the network and camp on a cell. For this to happen, the UE has to synchronize itself with the network at the frame and slot level. Afterward, it requires the information like Network ID (PLMN ID), Tracking Area ID, Cell ID and the Radio and Core Network capabilities for its network selection. The network broadcasts this information to help the UEs in their selection process.

The LTE network supports broadcasting of System Information in the form of MIBs and SIBs; Figure 4 outlines the system information broadcast procedure. Once the UE is synchronized with the network at the frame and slot level, it reads the broadcast information and selects it (PLMN and cell selection).

Figure 4. *System Information Broadcast*

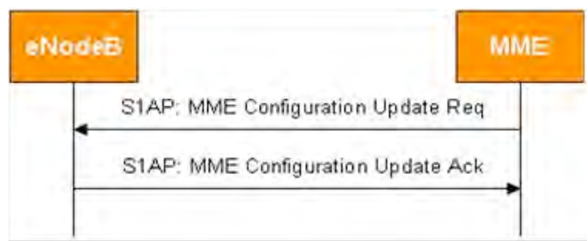

Figure 5. *MME Configuration Update Procedure*

- MIB contains cell bandwidth and information about PHICH and the SFN.
- SIB contains list of PLMN IDs, TAC, CellId, CSG Identity (optional), neighbor cell information, etc.
- eNodeB will get most of the elements from the MME in an S1AP MME Configuration Update
- Message on the S1 interface as shown in Figure 5. This happens after the S1 interface establishment between eNodeB and MME.

Random Access Procedure— System Access

The UE can utilize the services of the network once it is synchronized in both the downlink as well as the uplink direction. After the PLMN and Cell selection, the UE is synchronized with the network in the downlink direction and now it needs to synchronize with the network in the Uplink direction. The Random Access Procedure (RAP) over PRACH is performed by the UE for this purpose; RAP is characterized as one procedure independent of cell size and is common for both FDD & TDD. There are two types of RAPs: contention-based and non-contention-based.

Contention-based Random Access Procedure

In this mode, multiple UEs may attempt to access the network at the same time, thereby resulting in collisions. The contention is resolved among the contending UEs in the following 4-step process (Figure 6):

- *Step 1: Random Access Preamble on RACH in uplink*
  Preambles are grouped based on the size of the L3 message the, UE would like to transmit; this provides an indication of resource requirements for the UE to the network.

- *Step 2: Random Access Response generated by MAC on DL-SCH*
  This is an indication to the UE that the eNode B received its Preamble and conveys the resources reserved for this UE.

- *Step 3: First scheduled UL transmission on UL-SCH*
  The UE sends the RRC Connection Request using the resources given by the eNodeB in Step 2. In the RRC Connection request message, the UE sends its identifier to the network and it is used by the eNodeB to resolve the contention in the next step.

- *Step 4: Contention Resolution on DL*
  The eNodeB echoes back the received UE identifier to resolve the contention, and at this point the UE which has received its ID continues with the transmission while others will back off and try again.

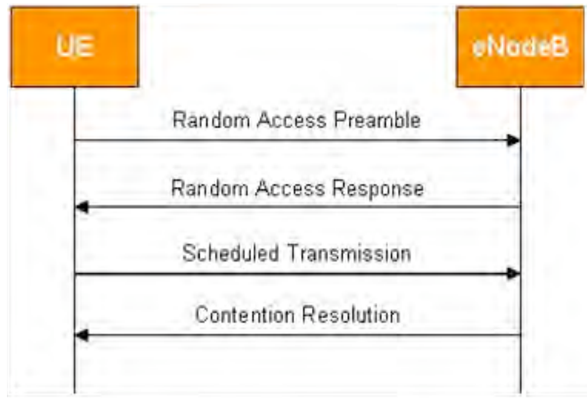

Figure 6. *Contention-Based Random Access Procedure*

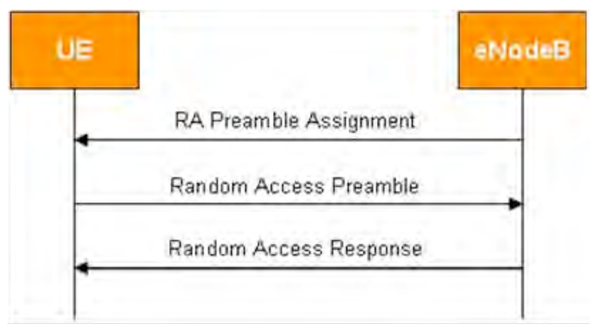

Figure 7. *Non-Contention-Based Random Access Procedure*

Non-Contention-Based Random Access Procedure

The network initiates this procedure in case of a handover of a UE from one eNodeB to another in order to keep handover latency under control. It usually reserves a set of RACH preambles for this purpose and will transmit one from that group to the UE. There are no collisions with other UEs because the eNodeB controls the procedure, which is shown in Figure 7.

Once the UE receives the assigned RA Preamble, it sends it to the eNodeB which responds back. Steps 3 and 4 given in the contention-based RAP are not required here.

RRC Connection and Initial Attach Procedure

After the Random Access procedure, if the UE is not already attached to the network it has to do so by initiating the attach procedure. Otherwise, the UE initiates the tracking area update if it changed its tracking area since the last update. For initiating any NAS procedure, the UE is required to establish an RRC connection with the eNodeB. The purpose of this procedure, depicted in Figure 8, is to request the resources from the network for its service needs.

RRC connection establishment involves Signaling Radio Bearer 1 (SRB1) establishment. The procedure is also used to transfer the initial NAS message from the UE to the MME via the eNodeB, the latter of which does not interpret the NAS message.

NAS Attach Procedure

To get NAS-level services (for example, internet connectivity) from the network, NAS nodes in the network have to know about the UE. To facilitate this; the UE has to initiate the Attach Procedure, which is mandatory for the UE at power on and also during the initial access of the network.

Once the attach procedure succeeds, a context is established for the UE in the MME, and a default bearer is established between the UE and the PDN GW and an IP address is allocated to it. Now that the UE has IP connectivity, it can start using IP-based internet services or IMS services if the IMS network is available and if the UE has a subscription for the same. The NAS Attach procedure is depicted in the Figure 9 and the steps are given below:

1. UE establishes the RRC Connection with the eNodeB.
2. The UE sends the ATTACH REQUEST message together with a PDN CONNECTIVITY REQUEST for the PDN (IP) connectivity on the established RRC Connection. As part of this, the eNodeB establishes the S1 logical connection with the MME for this UE.
3. If the Network is not able to identify the UE with the Identity given in the Attach Request message, it initiates the identification followed by Authentication and Security Mode procedures as given in Figure 10.

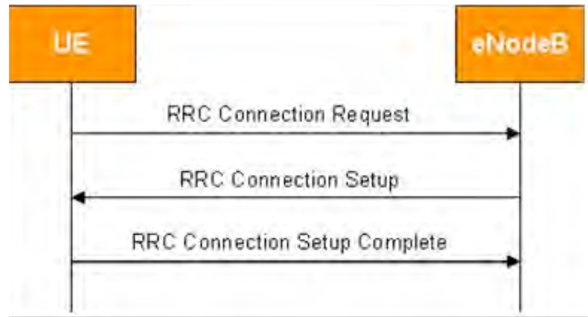

Figure 8. *RRC Connection Setup*

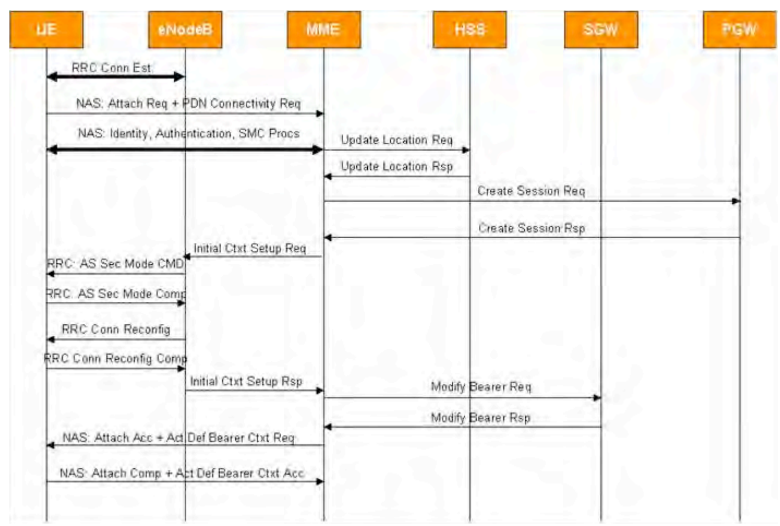

Figure 9. *Attach Procedure*

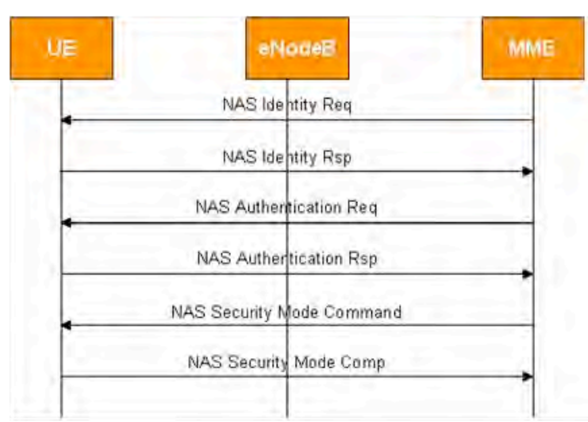

Figure 10. *NAS Common Procedures*

4. The MME update the HSS with the location of the UE using the Update Location request message using the Diameter protocol; it also requests the subscriber profile from the HSS using this message.

5. The HSS updates its database with the current location of the UE and sends the subscriber profile information to the MME in the Diameter Update Location Acknowledge message.

6. The MME now establishes an eGTP User Tunnel to establish the default bearer at the SGW; it sends a Create Session Request (eGTP-C protocol) toward the SGW.

7. The SGW creates the default bearer for this UE and requests the PGW to create a bearer for this UE between the SGW and the PGW to provide end-to-end bearer connectivity. The PDN-GW then creates the bearer and allocates an IP Address for the UE.

8. Once the SGW receives the response from the PGW, it responds with a Create Session Response to MME.

9. The MME now has to establish the bearer between the eNodeB and SGW. It sends the S1AP Initial Context Setup Request to the eNodeB to create a context for this UE, which includes the bearer Context and the security Context.

10. After receiving the Initial Context Setup Request, the eNodeB now establishes the security parameters with the UE by initiating the AS Security Mode Command Procedure.

11. The UE establishes the security parameters (parameters required for ciphering the Integrity protection) and sends the Security Mode Complete Message to the eNodeB. From now on, all the messages exchanged between the UE and eNodeB on the radio interface are ciphered as well as integrity-protected.

12. The eNodeB reconfigures the resources to the UE by sending an RRC Connection Reconfig Request to the UE. In this message, the eNodeB piggy-backs the Activate Default EPS Bearer Context Request NAS message to the UE.

13. The UE updates its RRC Connection configuration and responds back with an RRC Connection Reconfig Complete.

14. The eNodeB now sends the Initial Context Setup Response to the MME.

15. The MME sends the eGTP-C Modify Bearer Request to the SGW to update the eNB Tunnel Id for the default bearer.

16. After updating the information, the SGW responds with a Modify Bearer Response to the MME.

17. The MME now sends the Attach Accept and Activate Default Bearer Context Request NAS message to the UE.

18. If the MME has allocated a GUTI while sending the Attach Accept, the UE needs to process it and give back the Attach Complete as a response to it. The UE piggy-backs the Activate Default EPS bearer context Accept NAS message to the MME.

NAS Common Procedures

The MME can initiate the NAS common procedures during the initial Attach, Tracking Area Update and other dedicated NAS procedures. These procedures, depicted in Figure 10, are used to identify and authenticate the UE.

1. The MME sends the identity Request to the UE if it is unable to retrieve the UE profile from the HSS.

2. The UE responds back with its IMSI in the Identity Response message to MME.

3. After getting the valid IMSI from the UE, the network now authenticates the UE to ascertain whether the UE is genuine or not. The network and UE share a secret key (the Authentication Centre stores it in the network and the SIM card stores it in UE). Using this secret key and a random number, the network (AuC) computes a result and expects the UE to give back the same result as part of this procedure.

4. After receiving the parameters (RAND and A UTN from the network), the UE computes the result and gives it back to the network in the Authentication Response.

5. After successful authentication, the network initiates the Security mode command to encrypt the NAS messages between the UE and MME; this is to protect the privacy of the subscriber.
6. The UE agrees to the Security mode command and sends the response back to the Network. After this step, both the UE and the network will encrypt the NAS messages while sending and decrypt them while receiving. Similarly, NAS messages are integrity-protected from now onwards.

UE Initiated Detach Procedure

If the UE does not require services from the network, it needs to deregister itself with the network by initiating the detach procedure. One example for this is when the UE is switched off.

This detach procedure is initiated by the UE by sending a DETACH REQUEST message. The Detach type IE included in the message indicates whether detach is due to a "switch off" or not.

The network and the UE deactivate the EPS bearer context(s) for this UE locally without peer-to-peer signaling between the UE and MME. If the detach type is a "switch off" then the MME does not send the Detach Accept, otherwise it does send it to UE. While processing the Detach from the UE, the MME initiates the release of the EPS bearers in the network and it also clears the UE Context held at the eNodeB (not shown in Figure 11).

Tracking Area Update

After a successful attach to the network, the UE can roam freely in the current Tracking Area. If it detects a different tracking area, it needs to update the network with this new tracking area. Similarly, the network can request the UE to update its tracking area periodically, which helps the network in quickly locating the UE whenever a mobile-terminated call is received by the network for this UE since it can just page the UE in the last reported area.

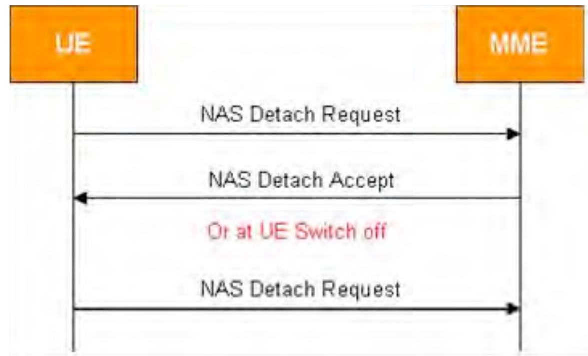

Figure 11. *UE Initiated Detach*

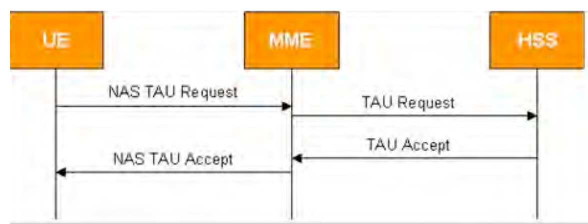

Figure 12. *Tracking Area Update without Authentication*

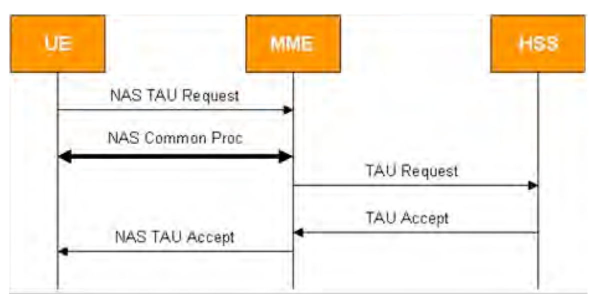

Figure 13. *Tracking Area Update with Authentication*

During the tracking area updating procedure, the MME may initiate an authentication procedure and setup a security context. The Tracking Area Update Procedure without the Authentication step is given in Figure 12, and the steps With Authentication and Security mode command (NAS Common Procedures) included are given in Figure 13.

Mobile-Originated Data Call

After successfully attaching to the network, the UE can request the services from the Network using the service request procedure. One example scenario is when the UE requests resources from the Network to initiate a data call; the UE can utilize the NAS service request procedure for this purpose. Another example of this procedure is to invoke MO/MT CS fallback procedures if they are supported by the network; the signaling messages involved in this procedure are given in Figure 14.

1. The UE establishes the RRC Connection with the eNodeB.

2. The UE sends the Service Request to the MME and requests (dedicated) bearer resources by including the Bearer Resource Allocation Req. As part of this, the eNodeB establishes the S1 logical connection with the MME for this UE. Note that the UE may also send the Bearer Resource Allocation Req to the MME as a standalone message at a later point in time too.

3. At this point the network can initiate an optional identification followed by Authentication and Security Mode procedures as given in Figure 10.

4. After the completion of the Authentication and Security Mode control procedures, the MME initiates the activation of default bearer with the SGW / PGW by initiating the eGTP-C Modify Bearer Req message toward the SGW.

5. After receiving the Modify Bearer Req, the SGW activates the required resources and forwards the Modify Bearer Req toward the PDN GW.

6. The PGW processes the Modify Bearer Req and activates required resources. Note that the IP Address is allocated during the Attach procedure, so it will not happen now. It responds back with the Modify Bearer Response to the SGW and the SGW forwards it to the MME.

7. The MME now initiates the Dedicated Bearer establishment by sending the eGTP-C Bearer Resource Command to the SGW.

8. The SGW process the Bearer Resource Command and forwards it to the PGW.

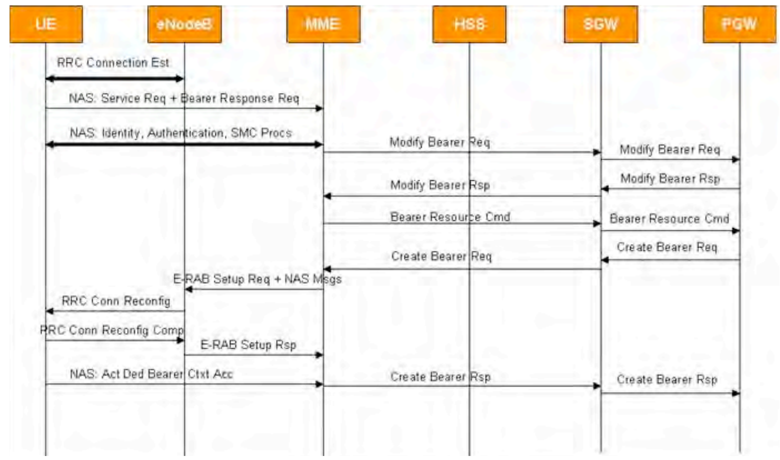

Figure 14. *Mobile-Originated Data Call*

9. The PGW responds with a Create Bearer Request toward the SGW after allocating the dedicated bearer resource (TFT initialization, etc).

10. The SGW process the Create Bearer Request and forwards to the MME for further processing.

11. The MME now sends the E-RAB Setup Req to the eNodeB to allocate the bearer between the eNodeB and the SGW; it piggy-backs the NAS Activate Dedicated EPS Bearer Context Req to the UE.

12. The eNodeB allocates the resources for the Radio Bearers using an RRC Conn Reconfig Req message to the UE. The eNodeB includes the received NAS message in it.

13. The UE establishes the Radio bearers and responds back with an RRC Connection Reconfiguration Complete Msg to the eNodeB.

14. Radio Bearers are established between the eNodeB and the UE by now, so the eNodeB sends the E-RAB Setup response to the MME.

15. The UE now sends the Activate Dedicated EPS Bearer Context Accept NAS message to the MME via the eNodeB.

16. The MME sends a Create Bearer Response to the SGW to complete the Dedicated Bearer Activation. The SGW forwards it to the PGW.

Mobile-Initiated Data Call Termination

Once the UE finishes the Data call it can trigger the release of the dedicated bearers by sending the Bearer Resource Modification Req message to the MME, which can then take care of releasing the dedicated bearer with the SGW and PGW.

1. The UE triggers the dedicated bearer release by sending the Bearer Resource Modification Request to the MME.
2. The MME initiates an EPS bearer context deactivation procedure by sending the eGTP-C Bearer Resource Command Msg to the SGW.
3. The SGW process the Bearer Resource Command and forwards it to the PGW.
4. The PGW initiates the Delete Bearer Req msg toward the SGW/MME to clear the requested bearer resources. The SGW forwards the same to the MME.
5. The MME initiates the E-RAB Release Command to the eNB to clear the bearer resources. It includes the NAS Msg: Deactivate EPS Bearer Context Req message for the UE.
6. The UE receives the NAS message from the eNB in the DL NAS procedure. It clears the bearer resources and sends a Deactivate EPS Bearer Context Accept to the MME.
7. The eNB now sends the E-RAB Release Response to the MME.
8. The MME sends the Delete Bearer Response to the SGW and the SGW forwards it to the PGW after clearing the bearer resources.
9. The PGW clears the requested Bearer resources.
10. If it is the release of the last dedicated bearer for this UE, the MME shall release the Context associated with this UE by sending an S1AP UE Context Release Command.
11. The eNodeB clears the Radio resources allocated to this UE by sending the RRC Connection Release message to the UE.

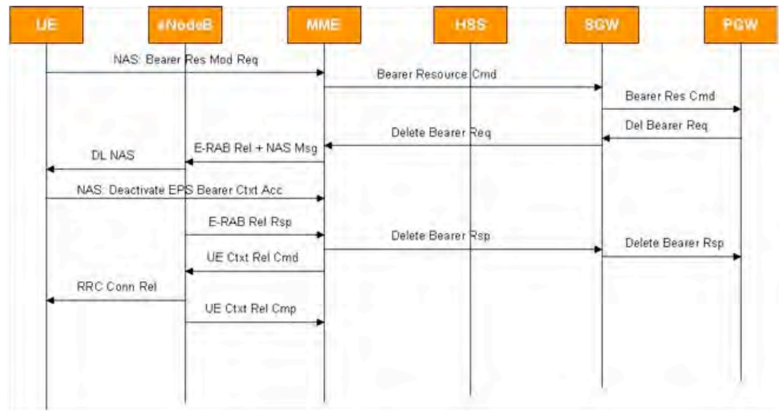

Figure 15. *Mobile-Initiated Data Call Release*

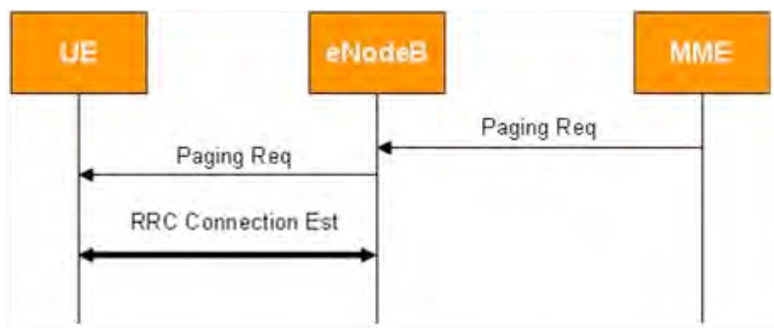

Figure 16. *Paging Procedure*

12. The eNodeB sends the UE Context Release complete message to the MME.

Paging

The paging procedure is used by the network to request the establishment of a NAS signaling connection to the UE. If there is an IP packet that comes for a UE from the external network to the PGW and if there is no dedicated bearer existing for the UE, it will forward the IP packet to the SGW on the default bearer. Once the packet has reached the SGW on the default bearer, the SGW detects the need to create a dedicated bearer and sends the Downlink Data Notification message to the MME in order the page the UE and create the dedicated bearers.

Now the MME has to ensure that the UE establishes an RRC connection, so the MME sends a Paging Request message to all eNodeBs associated with the last known Tracking Area.

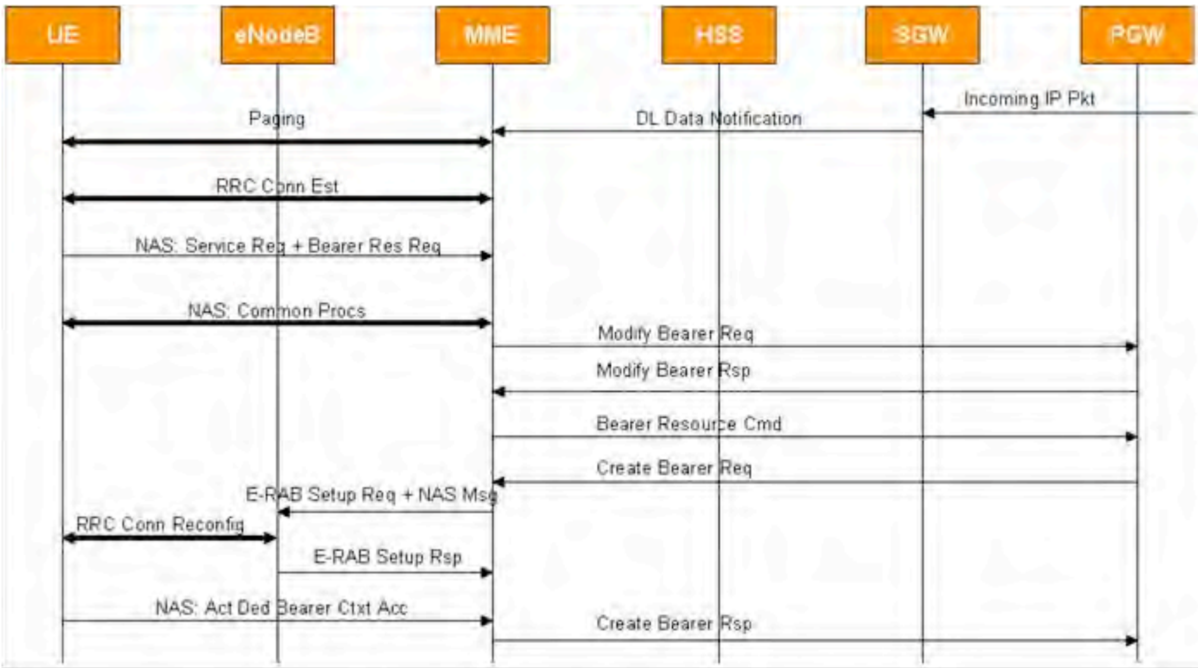

Figure 17. *Mobile Terminated Data Call*

Mobile-Terminated Data Call

For a UE-terminated call, the network sends the paging request to all the eNodeBs associated with the last known tracking area as discussed above. When receiving the Paging Request message from the MME, the eNodeB sends the paging message over the radio interface in the cells which are contained within one of the tracking areas provided in that message.

The UE is normally paged using its S-TMSI or IMSI. The Paging message also contains a UE identity index value in order for the eNodeB to calculate the paging occasions at which the UE listens for paging message. The procedure is depicted in Figure 17 and explained below:

1. The PGW/SGW receive the incoming IP packet addressed to a UE.
2. The SGW sends a DL Data Notification to the MME requesting dedicated UE bearer creation.
3. The MME now sends a Paging message to notify the UE about the incoming IP Packet.
4. Once the UE receives the Paging message on the radio interface, it establishes the RRC Connection with the eNodeB.
5. The UE sends the Service Request to the MME and includes the Bearer Resource Allocation Request to request the Dedicated Bearer Establishment.
6. From this point onward, the message sequence is the same as that outlined in the Mobile Originated Data Call. Please refer to Figure 14 and its message sequence explanation.

Conclusion

Existing 3G networks are not able to cope up with the rate of increasing demand for more and more bandwidth, which has led to development of new technology to satisfy subscribers' bandwidth needs. With over 100Mbps downlink and 50Mbps uplink (in the first phase), LTE promises to deliver high bandwidth on the move.

In this paper we covered the various signaling procedures executed by the UE and the network elements in LTE to provide services to the UE. All of these procedures were explained in the context of end-to-end signaling and the interactions of various network elements.

References

[1] 3GPP TS 36.300: "Evolved Universal Terrestrial Radio Access (E-UTRA), Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall Description; Stage 2"

[2] 3GPP TS 24.301: "Non-Access-Stratum (NAS) protocol for Evolved Packet System; Stage 3"

[3] 3GPP TS 24.302: "Access to the 3GPP Evolved Packet Core (EPC) via Non-3GPP Access Networks"

[4] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRAN); Radio Resource Control (RRC) Protocol Specification"

[5] 3GPP TS 36.401: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Architecture Description"

[6] 3GPP TS 36.413: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)"

[7] 3GPP TS 29.274: "Evolved General Packet Radio Service (GPRS) Tunneling Control Protocol for Control Plane (GTPv2-C) Stage 3"

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