BSc in Computer Engineering
CMP4204
Wireless Technologies

Lecture 11

4G LTE Cellular Mobile

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1. Revised Radio Spectrum for IMT-2000 and IMT-Adv

Changes in technology and the requirement for more and more spectrum is a major problem for the communication regulators. Here is a simplified spectrum allocation chart to give some idea of the various bands involved and the difficult problem for those in charge of spectrum management. Compare this to the chart in lecture 10 notes.

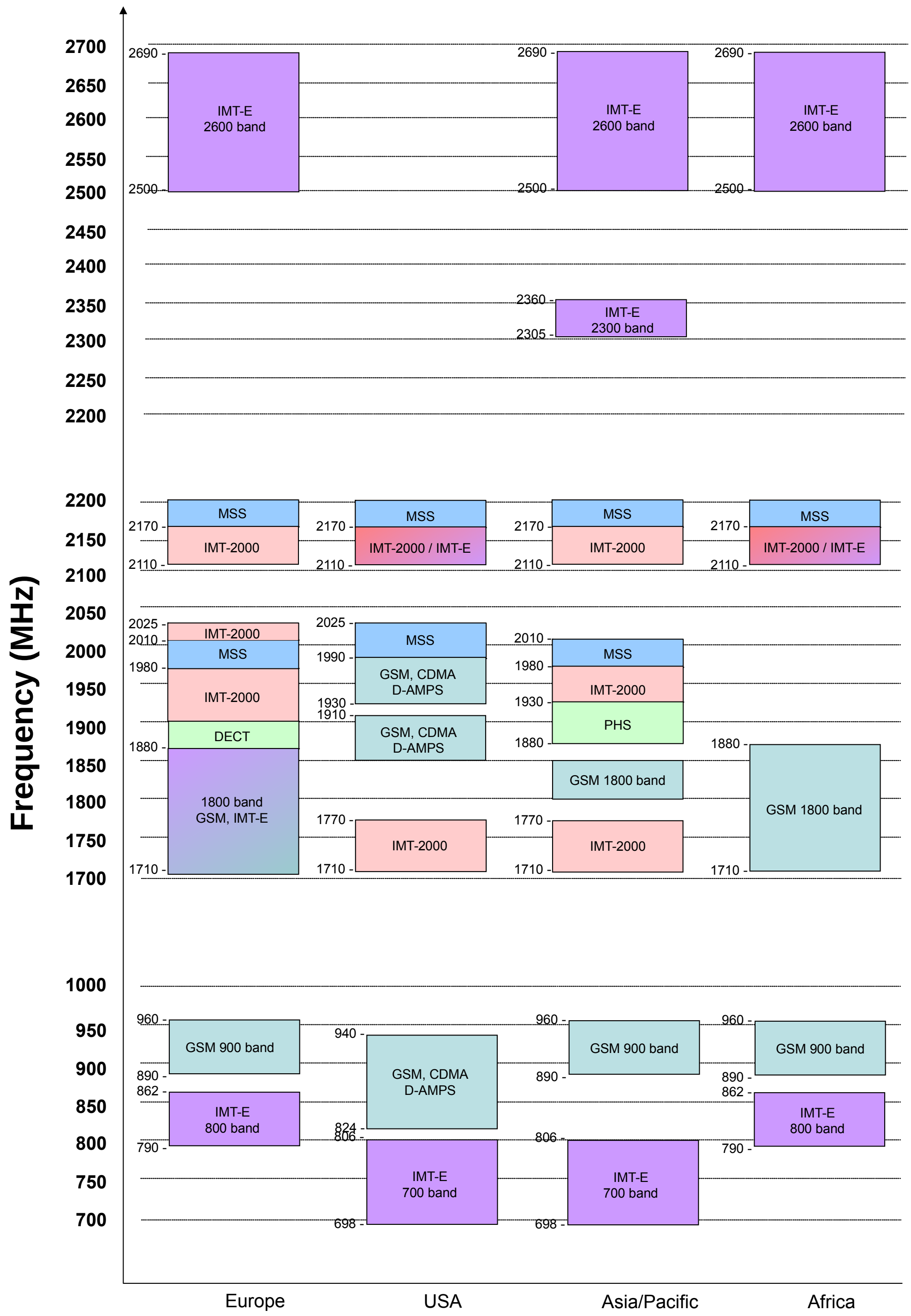

Illustration 1: Spectrum allocation

2. Multiple In, Multiple Out (MIMO)

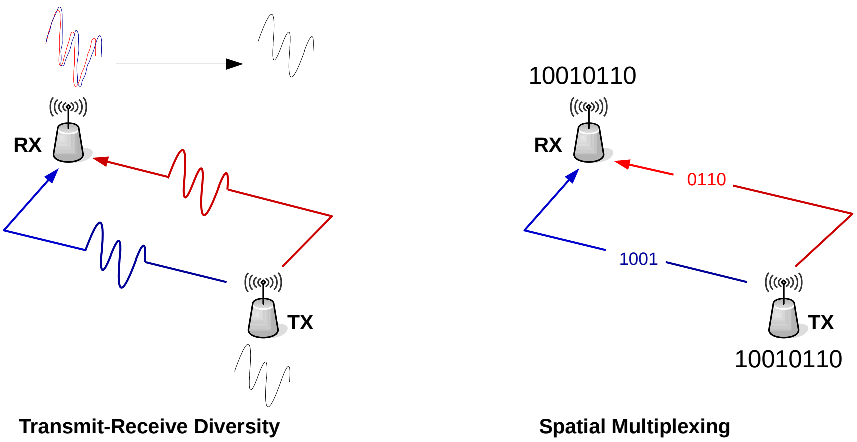

Illustration 2: MIMO functions

Multiple In, Multiple Out (MIMO) refers to an array of multiple antennas on the transmitter and on the receiver to send and receive multiple data streams simultaneously. These can be used to increase throughput giving increased spectral efficiency through spatial diversity.

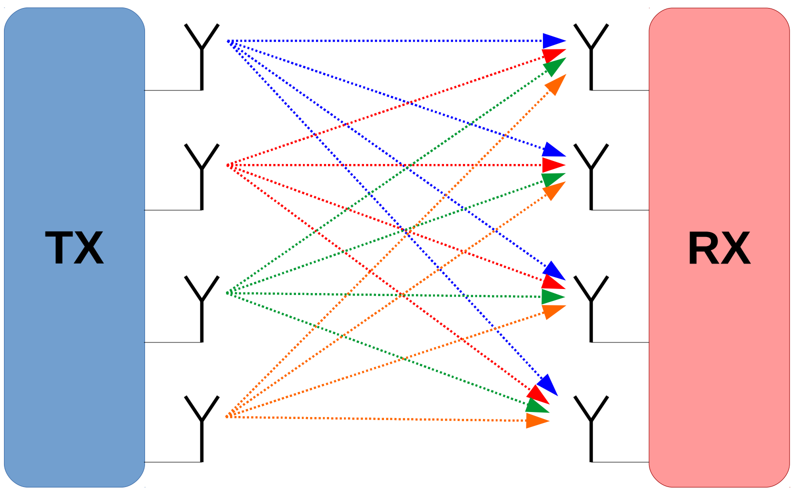

Illustration 3: 4X4 MIMO

If the spectral efficiency of a Single In, Single Out (SISO) system is in the region of 4 b/s/Hz then for a system with 4X4 MIMO with four antenna on the transmitter and four antenna on the receiver a spectral efficiency of 16.32 b/s/Hz can be achieved. This is a typical LTE solution. LTE-Advanced can even go up to 8X8 MIMO with eight transmission antennas and eight receive antennas where a spectral efficiency as high as 30 b/s/Hz can be achieved.

3. Long Term Evolution (LTE)

3GPP release 8 introduced Long Term Evolution (LTE), the step up from UMTS. LTE is considered a 4G standard. It provides 100Mb/s downlink and 50Mb/s uplink and low latency times. It includes all IP architecture in order to replace the GPRS elements. LTE uses OFDM in the RAN, together with the advanced MIMO antenna technologies introduced earlier. In addition to LTE, the 3GPP also defines an IP-based, flat network architecture.

The LTE radio interface provides improved coverage and throughput as it uses OFDM and MIMO to generate peak data rates in the downlink of 300 Mb/s and 75 Mb/s in the uplink with a Transfer latency of less than 5 mS.

Unlike UMTS LTE uses a flat all-IP Based Evolved Packet Core (EPC) which simplifies the overall system. Further to this LTE no longer handles voice as circuit switched traffic, instead it uses VoIP technology in IP Multimedia Core Network Subsystem (IMS). True voice calls in LTE are handled using Voice over LTE (VoLTE), SIP based VoIP.

3.1 Voice in LTE

Many operators were not ready to implement VoLTE and have two optional fallback methods. They can deploy LTE to handle data and continue to leverage existing 3G systems to circuit switch voice. There are two models:

- **Circuit-switched fallback (CSFB)**
  - Voice calls detected and transferred to circuit switched 3G MSC.
  - When there's an active voice call and data session, the device's radio will use HSPA+ for both the phone call and the data session.

- **Simultaneous voice and LTE (SVLTE)**
  - User Equipment (UE) uses LTE for data and circuit switched 3G for voice.
  - Handset needs to have two radios that are on simultaneously.
  - The problem that is obvious is that the power consumption would generally be higher as two radios are on when the voice call is ongoing.
  - Data speeds are not affected by ongoing voice call.

3.2 LTE system architecture

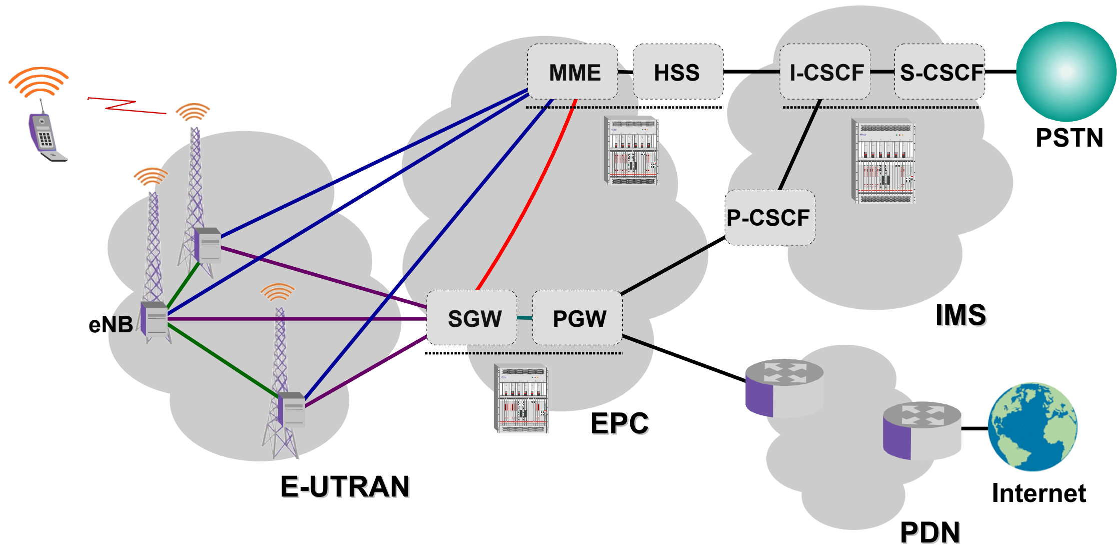

Illustration 4: LTE system architecture

As can be seen in Illustration 4 there are four major subsystems.

- Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
- EPC
- IMS
- Packet Data Network (PDN).

3.3 E-UTRAN

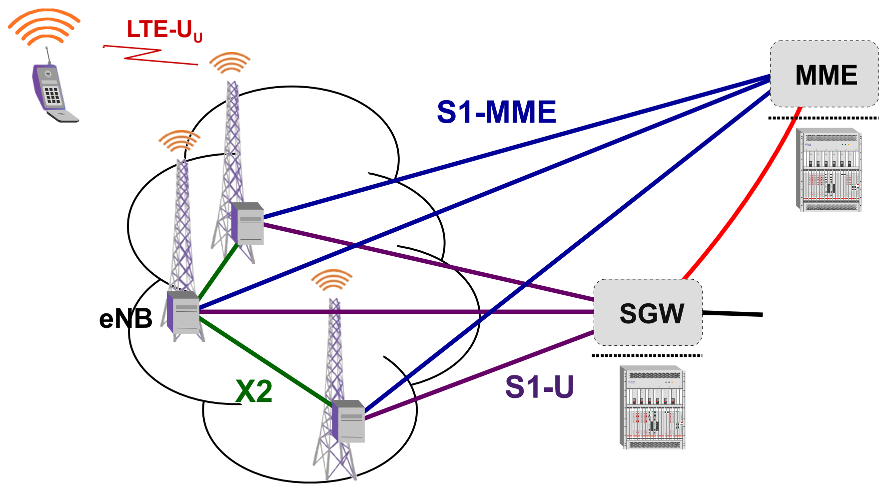

Illustration 5: LTE Radio Access Network (RAN)

As can be seen from Illustration 5 LTE simplifies the RAN by making the evolved NodeB (eNodeB or eNB) an IP device that connects to other eNBs in its domain via the X2 interface, to the core Mobility Management Entity (MME) via S1-MME and to the SGW via S1-U. The eNB communicates with the User Equipment (UE) over a new LTE U_U air interface.

- **LTE U_U** – This is the air interface between UE and eNB. Radio Resource Control (RRC) protocol over this interface handles the control plane signalling of Layer 3 between the UE and the eNB. The major functions of the RRC protocol include connection establishment and release functions, broadcast of system information, radio bearer establishment, reconfiguration and release, RRC connection mobility procedures, paging notification and release and outer loop power control.
- **X2** – This interface is used by the eNB to communicate to other eNBs. This uses IP/Stream Control Transmission Protocol (SCTP) as transport. X2-AP is the application protocol used by eNBs to communicate.
- **S1-MME** – The eNB and MME communicate using this IP interface. S1-AP is the application layer interface. The transport protocol used here is IP/SCTP.

3.3.1 Stream Control Transmission Protocol (SCTP)

SCTP is a transport layer protocol that provides a similar service to that of Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). It is defined in RFC 4960 and can in fact carry out the function of either UDP or TCP. SCTP is assigned the protocol number 132. It is message-oriented just like UDP but ensures reliable, in-sequence transport with congestion control just like TCP.

3.3.2 Evolved GTP (eGTP) – GTPv2

Another GPRS Tunnelling Protocol (GTP) variant. It is similar in functionality to GTP described earlier in this document but has extra functionality for LTE.

3.4 Evolved Packet Core (EPC)

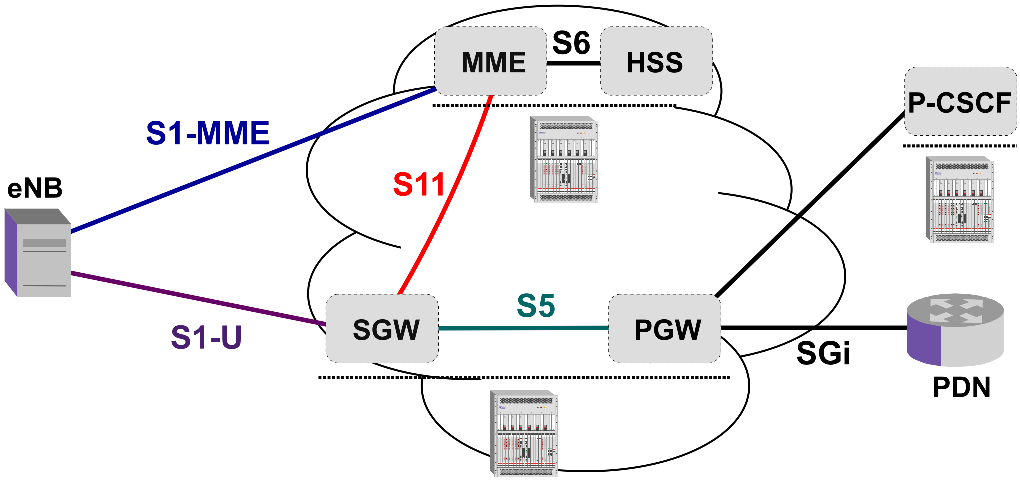

Illustration 6: Evolved Packet Core (EPC)

A major change in architecture from UMTS is the EPC.

- **Mobility Management Entity (MME)** - the control node for the LTE access network.
- **Serving Gateway (SGW)** - terminates the interface towards E-UTRAN. The SGW routes and forwards user data packets, while also acting as the mobility anchor for the user plane during inter-eNB handovers.
- **Packet Data Network Gateway (PGW)** - terminates the SGi interface towards PDN/IMS. The PGW provides connectivity from the UE to external packet data networks by being the point of exit and entry of traffic for the UE. It performs policy enforcement, packet filtering for each user, charging support, lawful interception and packet screening.
- **Home Subscriber Server (HSS)** – stores and updates the database containing all the user subscription information, including user identification and addressing in the form of International Mobile Subscriber Identity (IMSI) and E164 telephone number. It also holds the associated user profile information like service subscription states and subscribed Quality of Service (QoS) information. It is also responsible for the generation of security information from user identity keys for mutual network-terminal authentication as well as radio path ciphering and integrity protection.
- **S11** – The IP interface between MME and SGW. GTPv2 is the tunnelling protocol used at the application layer. GTPv2 runs on UDP transport.
- **S5** - The interface between the SGW and the PGW. This is an IP interface and has two variants.
  - GTP interface.
  - Proxy Mobile IP (PMIP) interface is used to support non-trusted 3GPP network access.
- **S6** – The IP/SCTP interface between the MME and the HSS. Subscription and AAA data are transferred over this interface.

3.4.1 Proxy Mobile IP (PMIP)

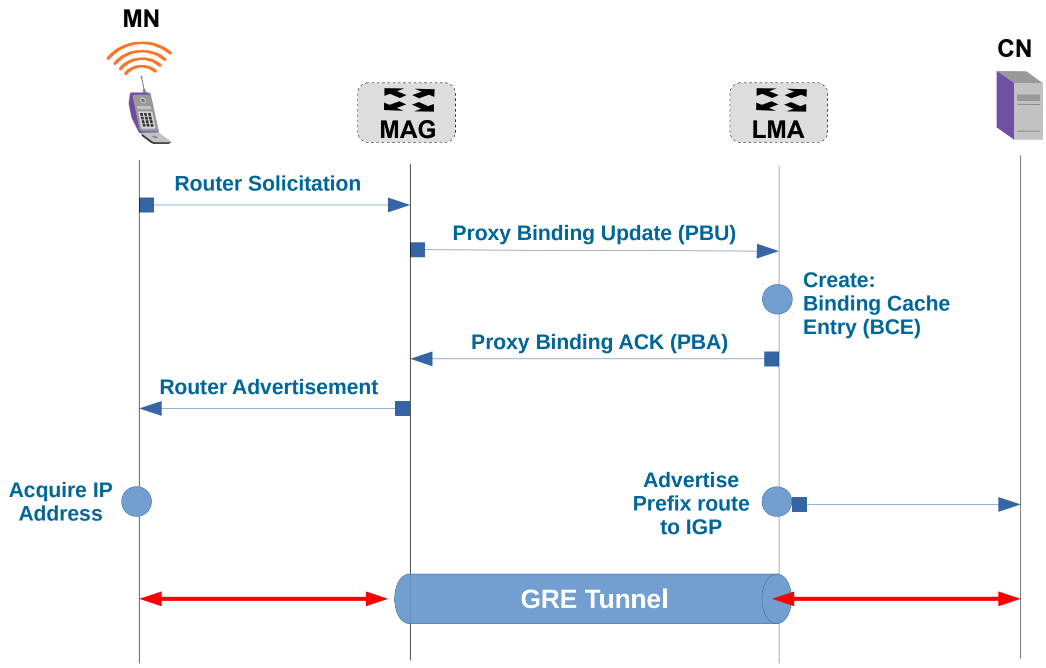

Illustration 7: Proxy Mobile IP (PMIP)

PMIP is defined in RFC 5213. It is a tunnelling protocol that permits a Mobile Node (MN) to access a Core Node (CN). It has the following functional entities:

- Local Mobility Anchor (LMA)
- Mobile Access Gateway (MAG)
- Mobile Node (MN)
- Correspondent Node (CN).

When an MN tried to get an IP address (IPv6 Router Solicitation in Illustration 7) the MAG sends a Proxy Binding Update (PBU) to the LMA to get a Binding Cache Entry (BCE) created. Once the LMA has completed this it responds with a Proxy Binding ACK (PBA) and the MAG responds to the MN with a Router Advertisement. The LMA advertises the BCE prefix to the Interior Gateway Protocol (IGP) while the MN acquires an IP address. A GRE tunnel is established between MAG and LMA to carry traffic from the MN to the CN.

3.5 IP Multimedia Subsystem (IMS)

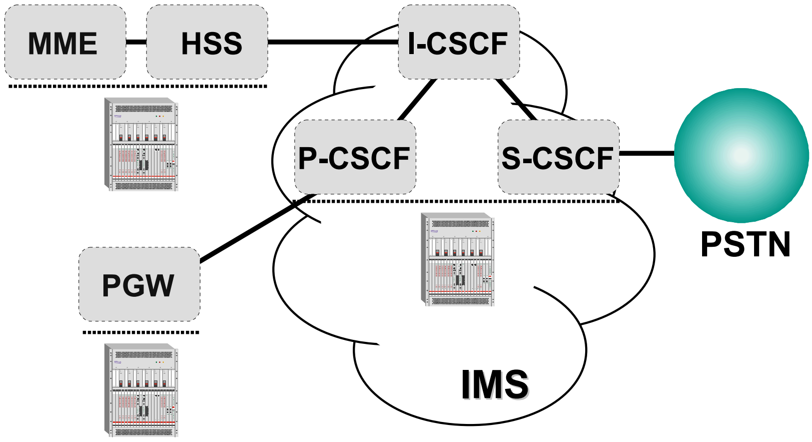

Illustration 8: IP Multimedia Subsystem (IMS)

IMS delivering IP multimedia services to the LTE architecture. As LTE uses an all IP madel with no circuit switched MSC an alternative system is required. Voice is handled in LTE over an IP packet-switched network.

IMS uses SIP as the multimedia signalling protocol and therefore a number of the elements in that subsystem are in fact SIP proxy servers. Here is a summary of the most important elements.

- **Session Border Controller (SBC)** is a VoIP firewall function that is involved in setting up, conducting, and tearing down SIP calls.
- **Call Session Control Function (CSCF)** is a set of session controllers within IMS.
- **Proxy-CSCF (P-CSCF)** is the entry point to the IMS domain and serves as the outbound proxy server for the UE. It also acts as a specialist SBC to protect the IMS network. The UE attaches to the P-CSCF prior to performing IMS registrations and initiating SIP sessions. The P-CSCF may be in the home domain of the IMS operator, or it may be in the visiting domain, where the UE is currently roaming. Attachment to the P-CSCF is necessary for the UE for initiating IMS registrations and sessions.
- **Interrogating-CSCF (I-CSCF)** is the SIP Proxy function at the edge of the IMS domain. Can be found by UEs via DNS. and use it as a forwarding point (e.g., registering) for SIP packets to this domain. It uses the HSS to retrieve the IP address of the S-CSCF and assign it to a user performing SIP registration, it also forwards SIP request or response to the S-CSCF.
- **Serving-CSCF (S-CSCF)** is a SIP proxy server assigned to UE by I-CSCF depending on the user profile from the HSS. It is always located in the UEs home network. It handles SIP registrations, which allows it to bind the user IP address and the SIP address. It sits in the path of all signalling messages of the locally registered users, and can inspect each message and decide to which application server the SIP message will be forwarded, in order to provide services. There can be multiple S-CSCFs in the network for load distribution and high availability reasons.

3.6 UE attach to the network

When a UE connects to the network it must *attach*.

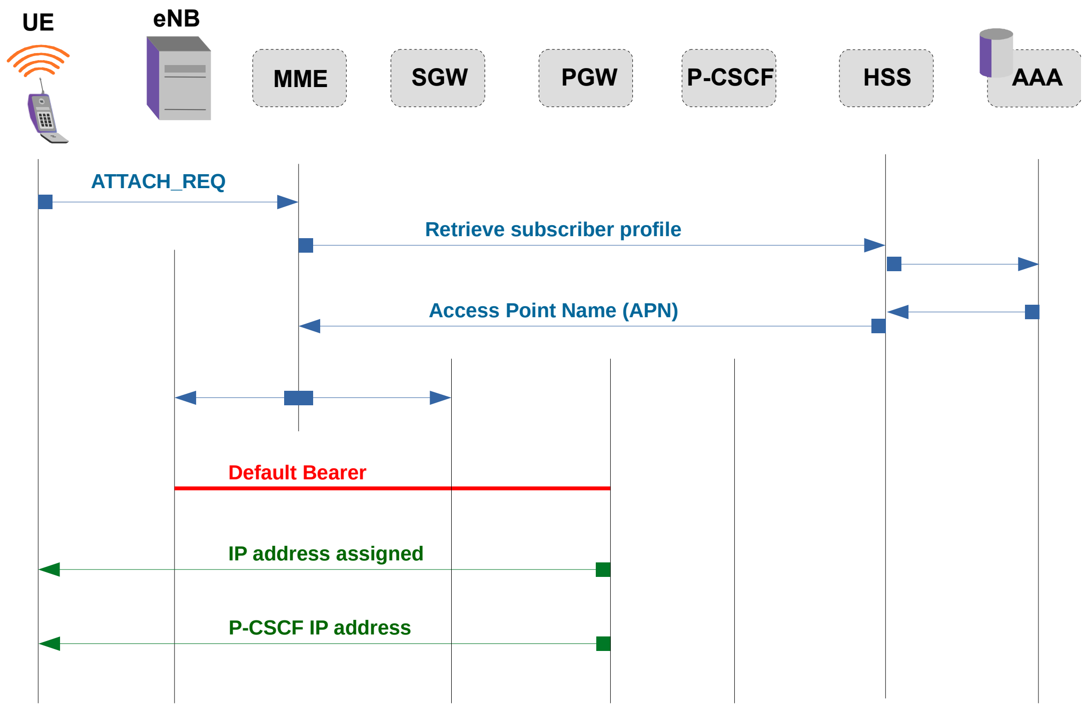

Illustration 9: UE attach to the network

When the UE connects to the network it sends an *ATTACH_REQ* message to the MME. The MME requests the subscriber profile from the HSS from the HSS and received the UE *Access Point Name (APN)*. From this information it informs the eNB and SGW of the UE connection. The SGW assigns a particular PGW based on the UE profile and a connection Default Bearer is created between the eNB and PGW for this particular UE. The PGW assigns an IP address to the UE and the IP address of the *Proxy-Call Session Control Function (P-CSCF),* the entry point to the IMS that will handle VoIP calls from the UE.

3.7 Voice over LTE (VoLTE)

VoLTE is based on the IMS network, with specific profiles for the control and media planes of voice service on LTE. With VoLTE the control and media planes of the voice service is delivered as in the LTE data bearer channels. This is necessary as LTE does not support legacy circuit-switched voice channels. As VoLTE uses small optimised packet headers, bandwidth is freed up with the result that VoLTE has up to three times more voice and data capacity than 3G UMTS and up to six times more than 2G GSM.

3.7.1 UE Register with S-CSCF

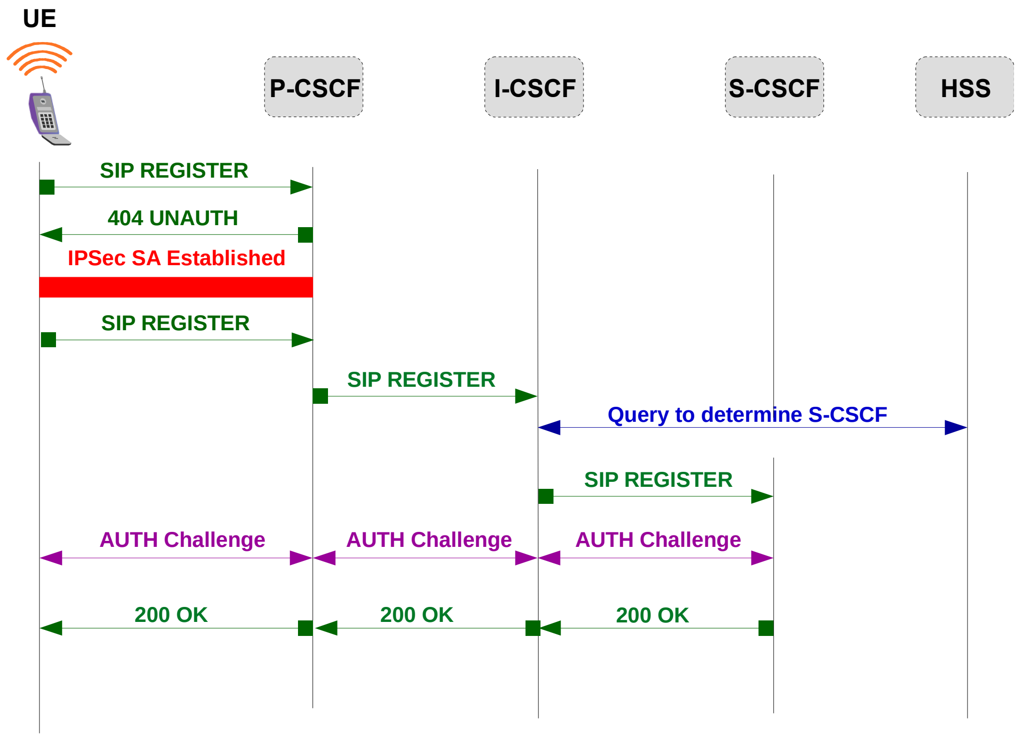

Illustration 10: UE Registers with S-CSCF

During the UE *attach* an IP address was supplied for the P-CSCF which is the guardian of the IMS domain. The UE will attempt to perform a *SIP REGISTER* so it is in a position to make voice calls. An initial attempt fails until and IP Security (IPSec) Secure Association (SA) has been established to protect voice traffic. The *SIP REGISTER* now receives a *200 OK* message. The P-CSCF forwards the SIP Register to the I-CSCF who queries the UE profile with the HSS to determine the correct S-CSCF to use. Upon determining the S-CSCF address it also forwards the *SIP REGISTER*. The S-CSCF AUTHenticates the UE and this is passed down and back up the chain to the UE. The S-CSCF acknowledges with a 200 OK message which is passed along the chain to the UE.

3.7.2 UE making a voice call

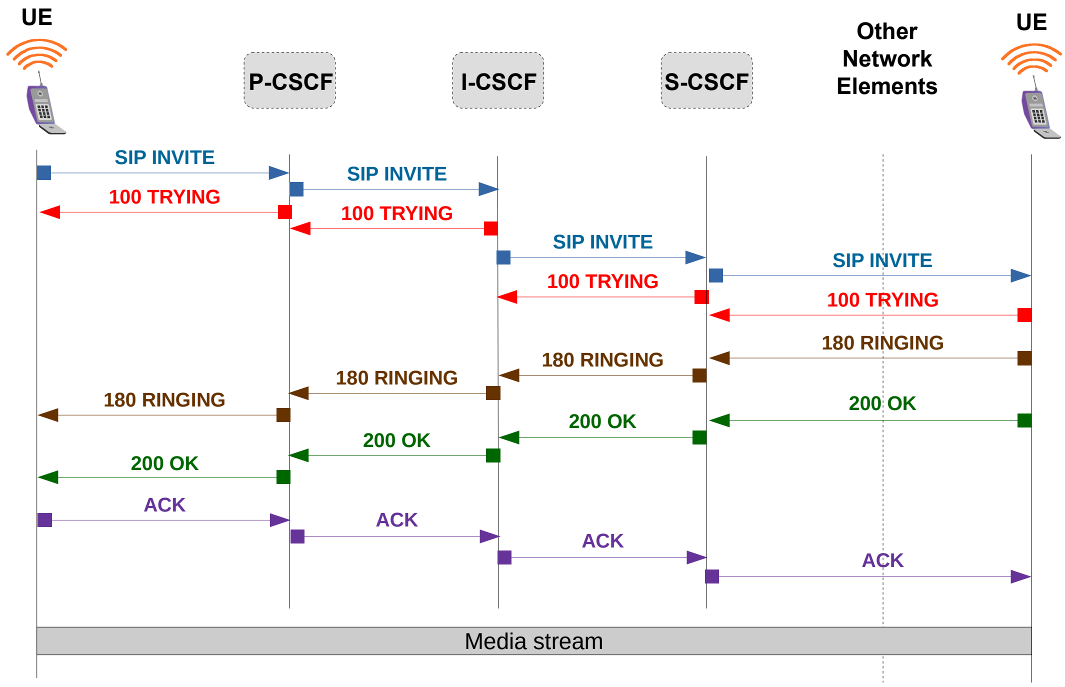

Illustration 11: UE making a voice call

The UE wishes to make a call so it sends a *SIP INVITE* to the P-CSCF. It responds with a *100 TRYING* message while forwarding the message to the I-CSCF who in turn forwards it to the S-CSCF. The dotted line represents other network elements that could exist, another operator, a fixed line operators Media Gateway (MG) infrastructure for example. The *SIP INVITE* is forwarded to the other side UE and a *180 RINGING* message is passed down the chain so the originating UE can playing a ringing tone. Upon the receiving UE picking up the call a *200 OK* message is passed along the chain which is responded to with an *SIP ACK* message and the media stream is established. The conversation can begin.

4. Self-test Quiz

1. What are the differences between a 3G NodeB and an LTE eNB ?
2. Describe the process of a UE attaching to the network ?
3. Describe how a telephone call is established using VoLTE ?