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LTE Fundamentals

The Complete Course

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Content:

1. Brief history about wireless ecosystem.
    - What is LTE (Long Term Evolution) ?
    - How is it different from older technologies ?

2. Network architecture in LTE
    - Radio Access network (RAN)
    - Evolved Packet Core (EPC)
    - Bearers in LTE

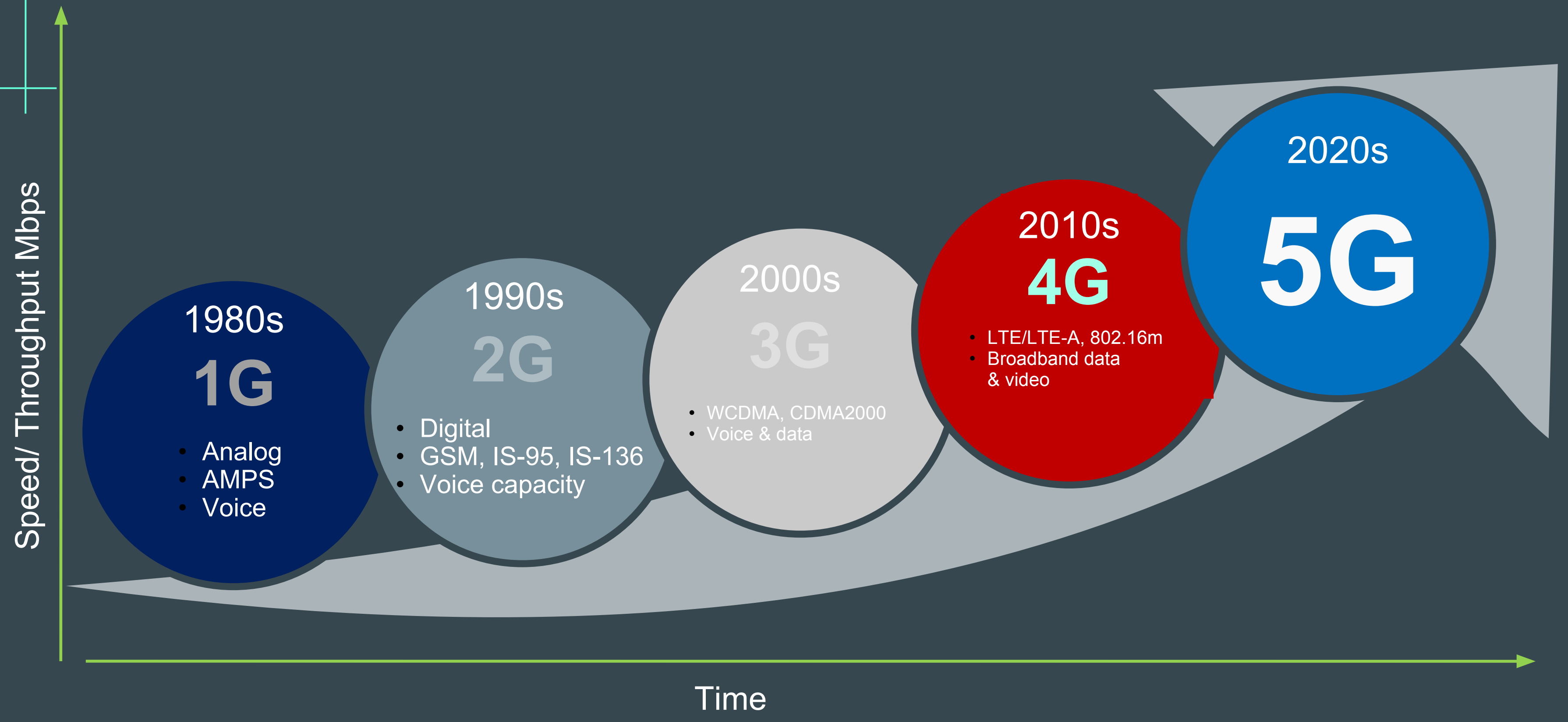
3. Interfaces in LTE
4. Life Cycle of a UE

Content contd:

5. LTE RAN overview
    - Architecture and requirements
    - Channel bandwidths and operating bands
    - OFDMA and SC-FDMA
    - Frequency (LTE-FDD) and time division duplexing (LTE-TDD)
    - Multiple Antenna techniques in LTE
    - Channels in LTE and protocol Stack

6. LTE EPC overview
    - Architecture
    - Functions of various elements in EPC

Brief history about wireless ecosystem



Speed/ Throughput Mbps
1980s
1G
• Analog
• AMPS
• Voice
1990s
2G
• Digital
• GSM, IS-95, IS-136
• Voice capacity
2000s
3G
• WCDMA, CDMA2000
• Voice & data
2010s
4G
• LTE/LTE-A, 802.16m
• Broadband data & video
2020s
5G
Time

Comparison of Wireless technologies

Generation	1G	2G	3G	4G	5G
Deployment	1970-84	1980-89	1990-2002	2000-18	2020+
Throughput	2Kbps	14-64 Kbps	2 Mbps	200 Mbps	1Gbps+
Services	Analog Voice	Digital Voice SMS,MMS	Integrated HD Video and data	High Speed Data, Voice over LTE (VoLTE)	Ultra-low Latency, massive IoT,V2V
Underlying Technology std.	AMPS,TACS	D-AMPS,CDMA (IS-95)	CDMA2000,EVDO,W-CDMA,HSPA+	LTE, VoLTE, LTE Advanced, LTE Advanced Pro	5G-NR

How is LTE different from the previous technologies ?

How is LTE different ?

LTE benefits (Compared to 3G) include :

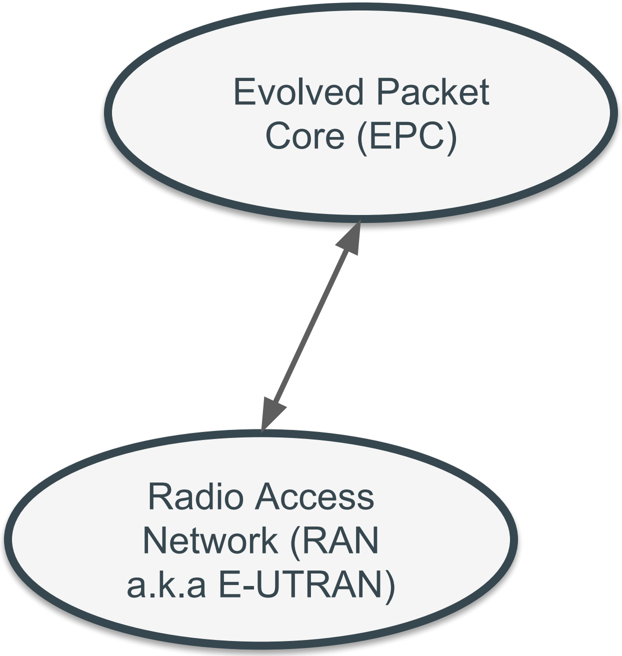
- High Data rates
- Reduced Latency
- Improved end-user throughputs for applications such as a Voice and Video
- Flexibility of radio frequency deployment since LTE can be deployed in various bandwidth configurations (1.4, 3, 5, 10, 15, 20 MHz)
- Multiple Input Multiple Output (MIMO)
- Flat all-IP network with fewer network elements which leads to lower latency.
- Offers a TDD solution (LTE-TDD) in addition to FDD (LTE-FDD)

Network Architecture in LTE

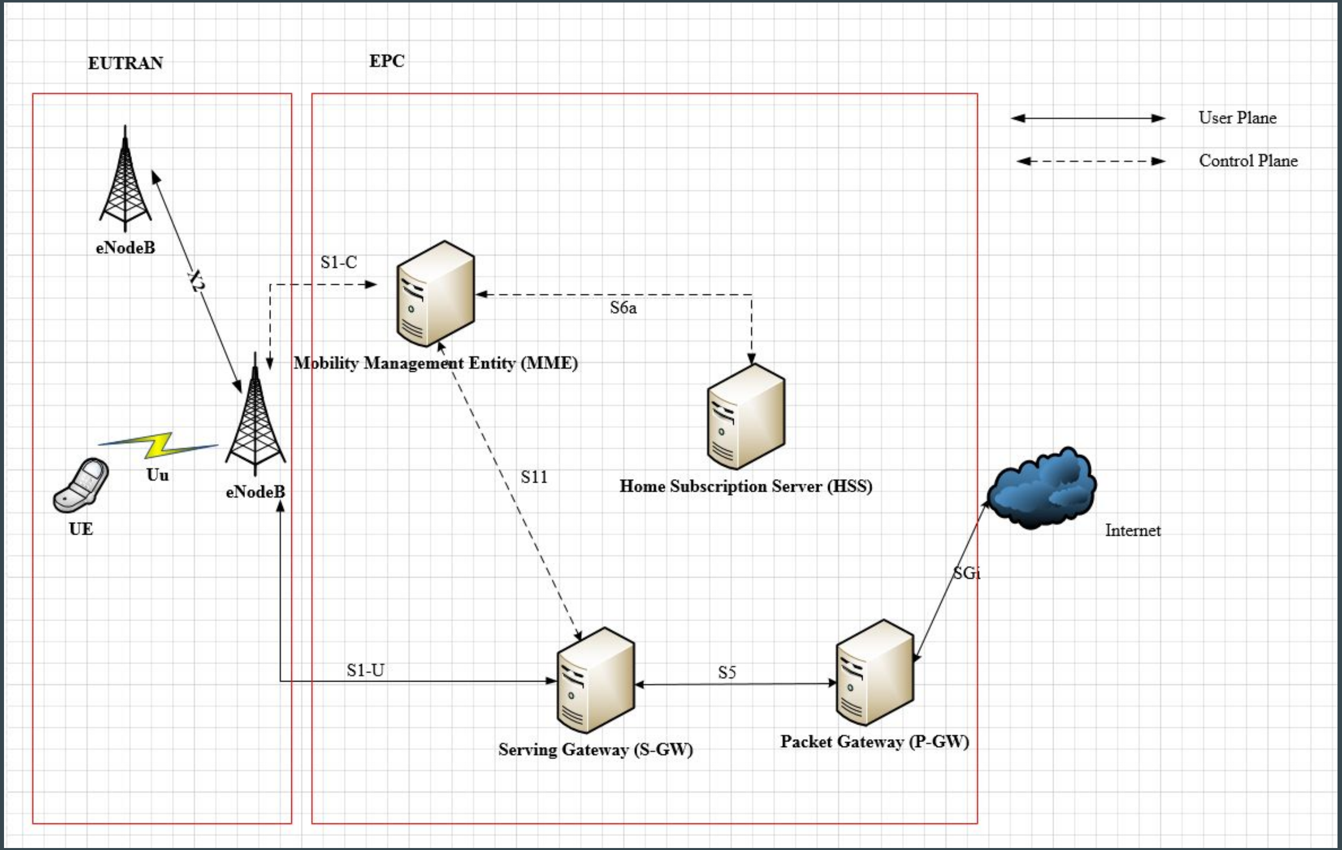
Network Architecture in LTE:

LTE architecture is composed of 2 parts –

- Radio Access Network: Evolved UTRA Network (E-UTRAN)
- Core Network Architecture : Evolved Packet Core (EPC)



Network Architecture in LTE contd:

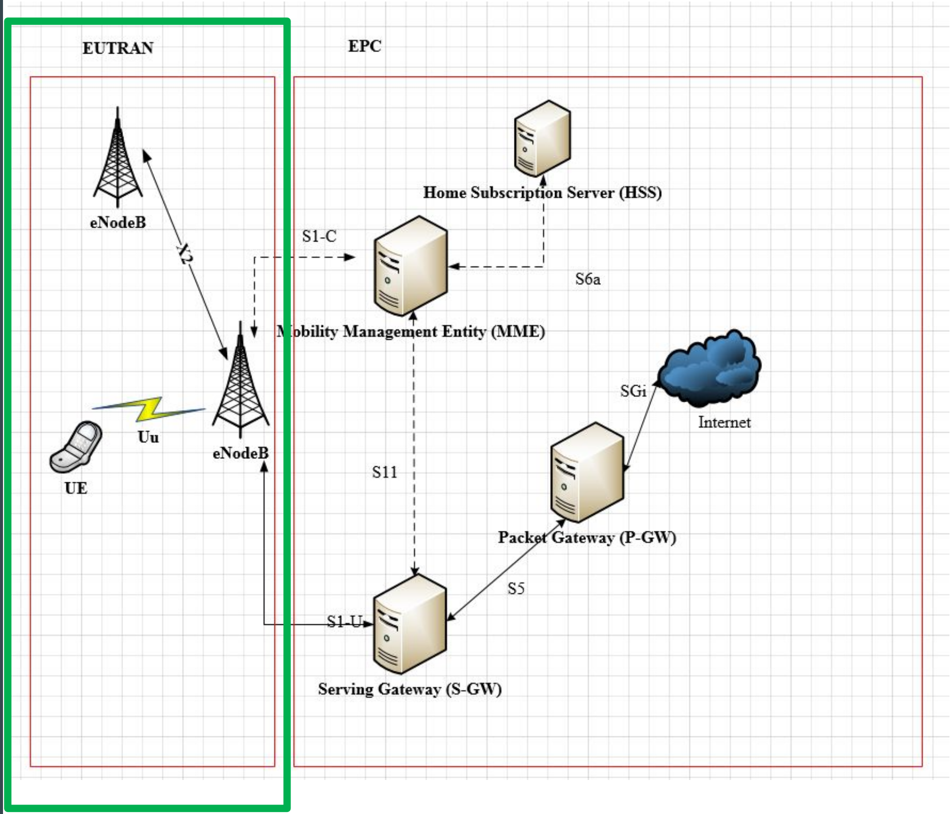


Network Architecture in LTE contd.

EUTRAN:

Evolved NodeB (eNodeB)

- Radio Resource management
- Synchronization and Interference control
- MME Selection among MME Pool
- Routing of User Plane data from/to S-GW
- Encryption/Integrity protection of user data
- IP Header Compression

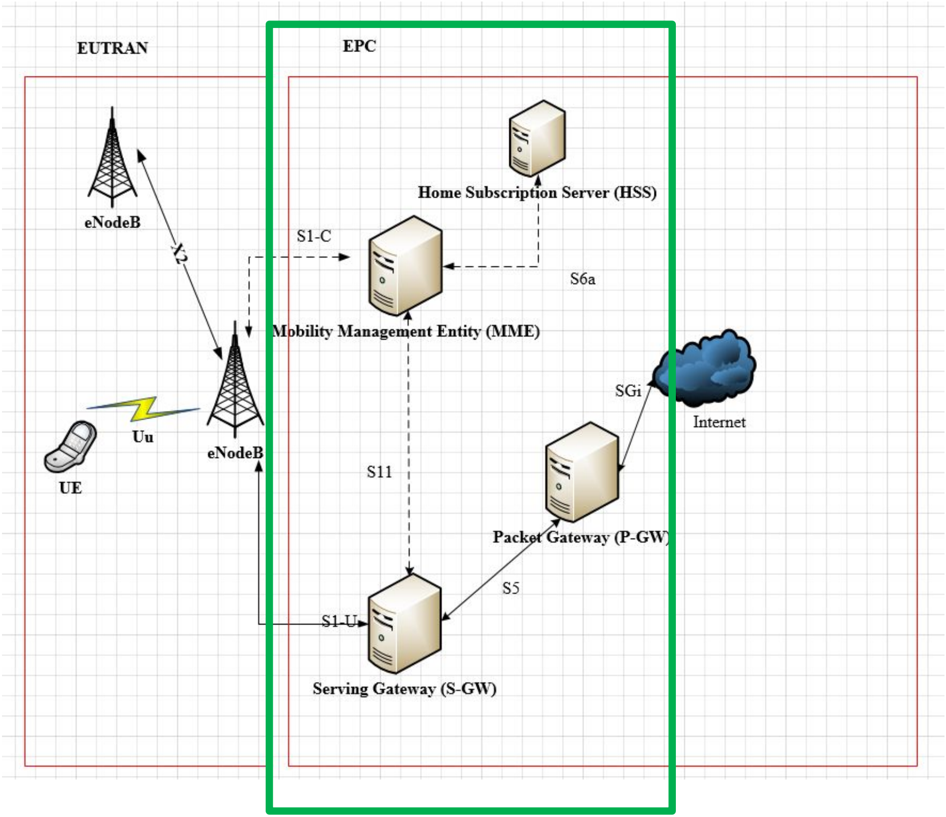


Network Architecture in LTE contd.

EPC:

Mobility Management Entity (MME)

- NAS (non-access stratum) signaling and its security
- Tracking Areas List management
- PDN GW and SGW selection.
- Roaming and Authentication
- EPS bearer management
- Signaling for mobility management between 3GPP RANs

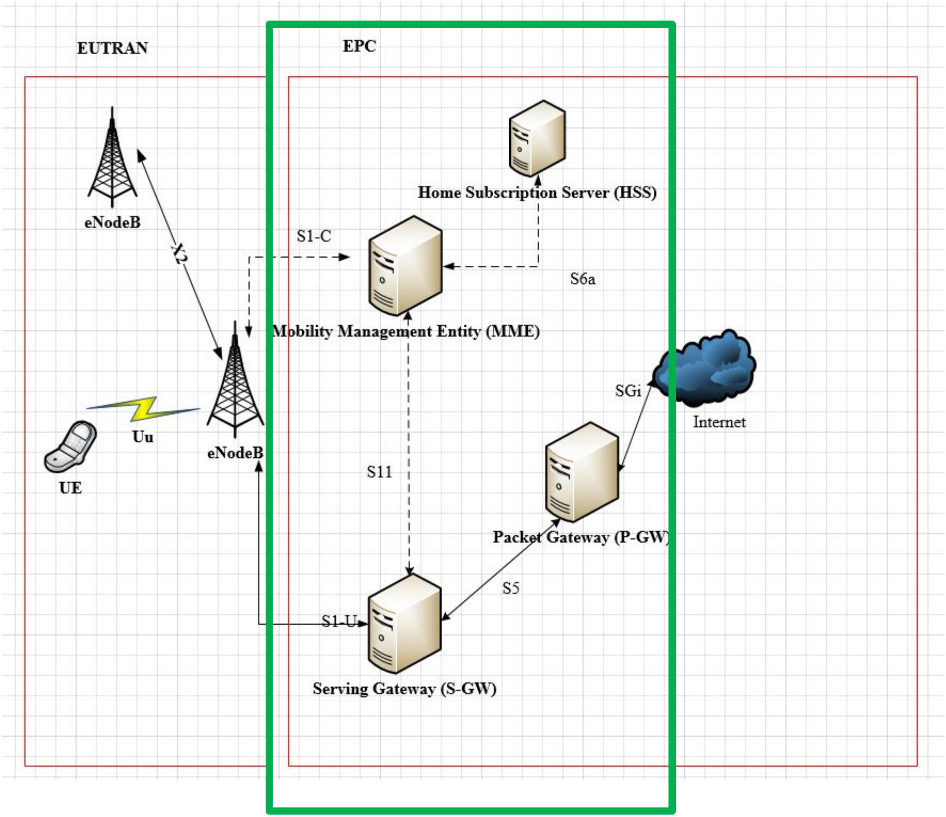


Network Architecture in LTE contd.

EPC Contd.:

Home Subscription Server (HSS)

- User Authentication
- Subscription/Profile management –
  - Roaming
  - Speed/throughput limits

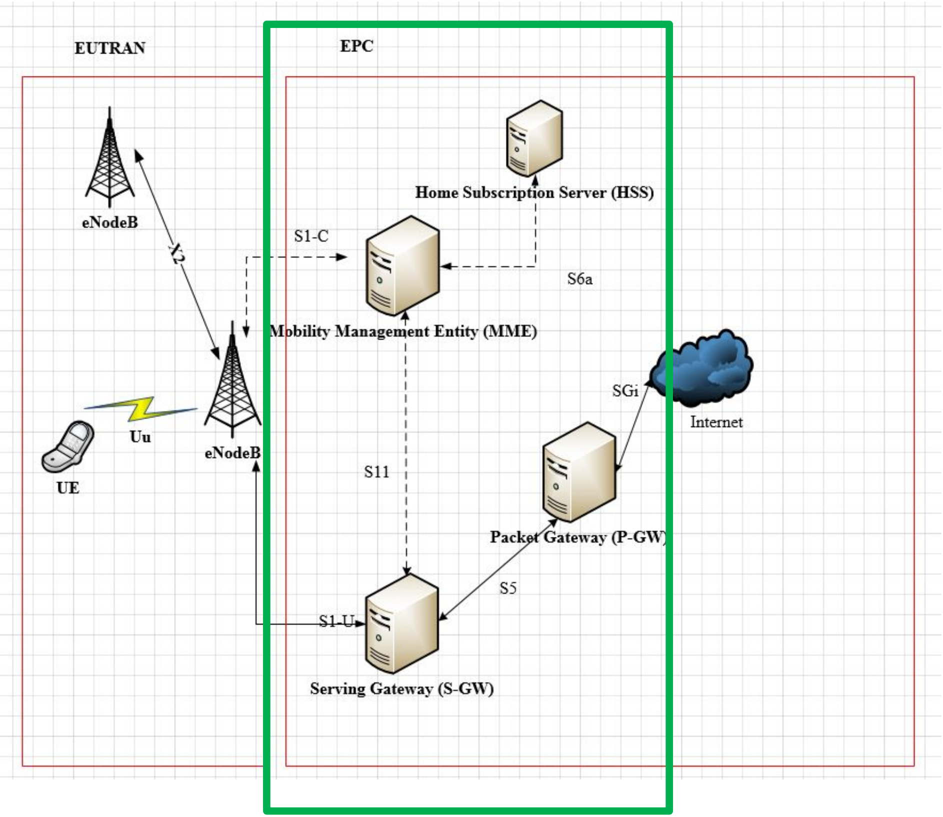


Network Architecture in LTE contd.

EPC Contd.:

Serving Gateway (S-GW)

- Packet routing and forwarding
- EUTRAN Idle mode DL packet buffering
- EUTRAN and inter-3GPP mobility anchoring
- UL and DL charging per UE, PDN and QCI

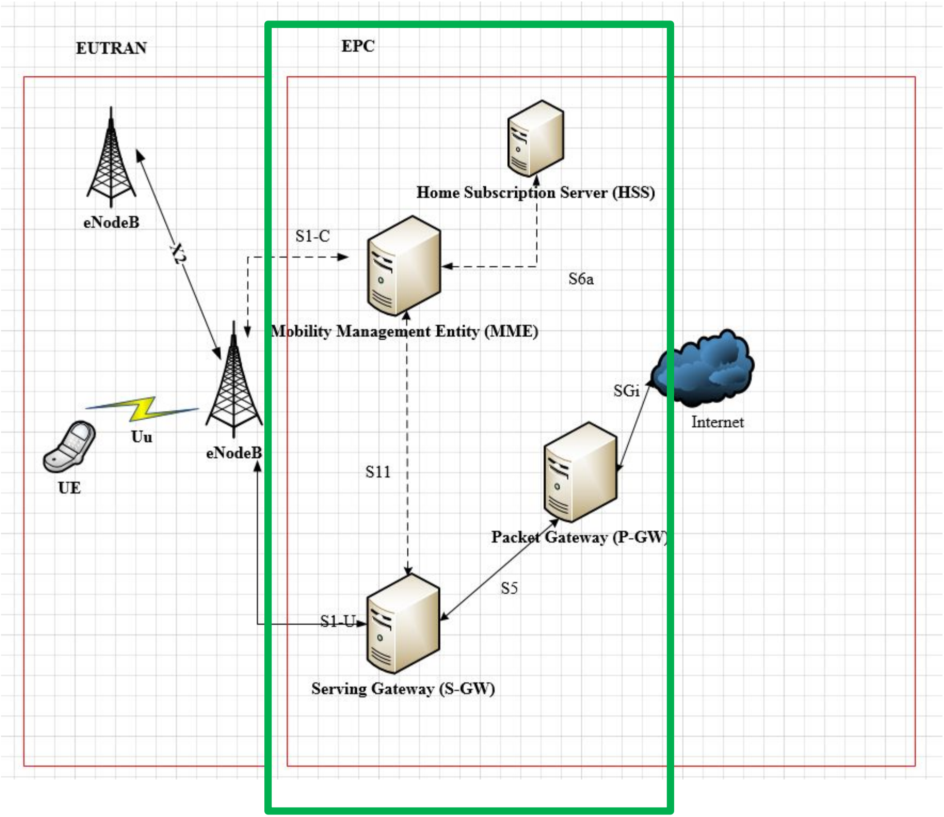


Network Architecture in LTE contd.

EPC Contd:

Packet Data Network Gateway (P-GW)

- IP Address allocation
- Packet filtering and Policy enforcement
- Transport Level QoS mapping and marking.
- User Info anchoring for 3GPP and non-3GPP handovers.



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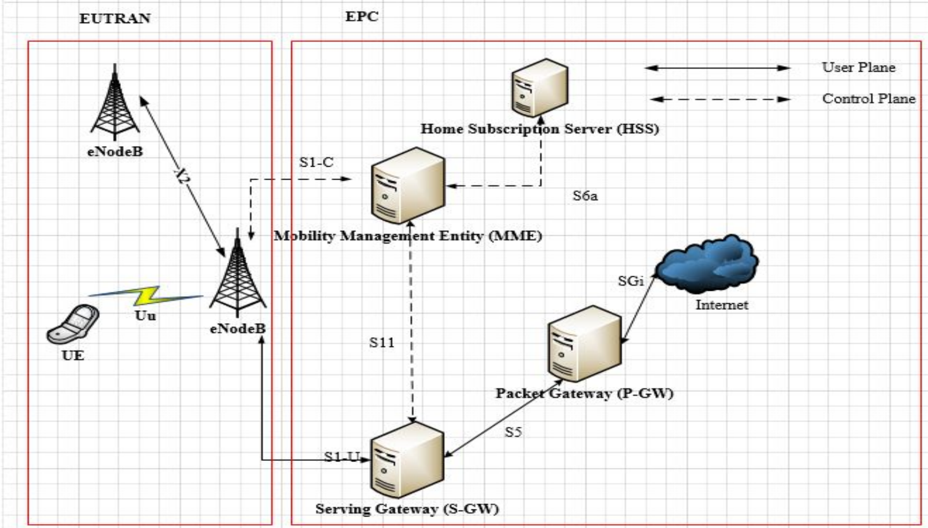


eNodeB Functions:

- Radio Resource management, radio bearer control, radio admission control, connection mobility control, uplink/ downlink scheduling
- IP header compression and ciphering of the User data stream.
- MME selection
- Paging
- CMAS

MME Functions:

- Non-Access Stratum (NAS) signaling (attachment, bearer setup/deletion)
- NAS signaling security
- Signaling for mobility between 3GPP access networks
- Idle mode user tracking
- Tracking Area list mgmt.
- PDN gateway, S-GW selection
- Roaming – S6a interface to HSS
- Authentication

Serving Gateway Functions:

- Local mobility anchor for inter-eNodeB handover.
- EUTRAN downlink packet buffering-while idle UE is being paged.
- Lawful intercept
- Packet routing and forwarding
- Transport level packet marking (UL/DL)
- Accounting for inter-operator charging.
- Accounting per UE

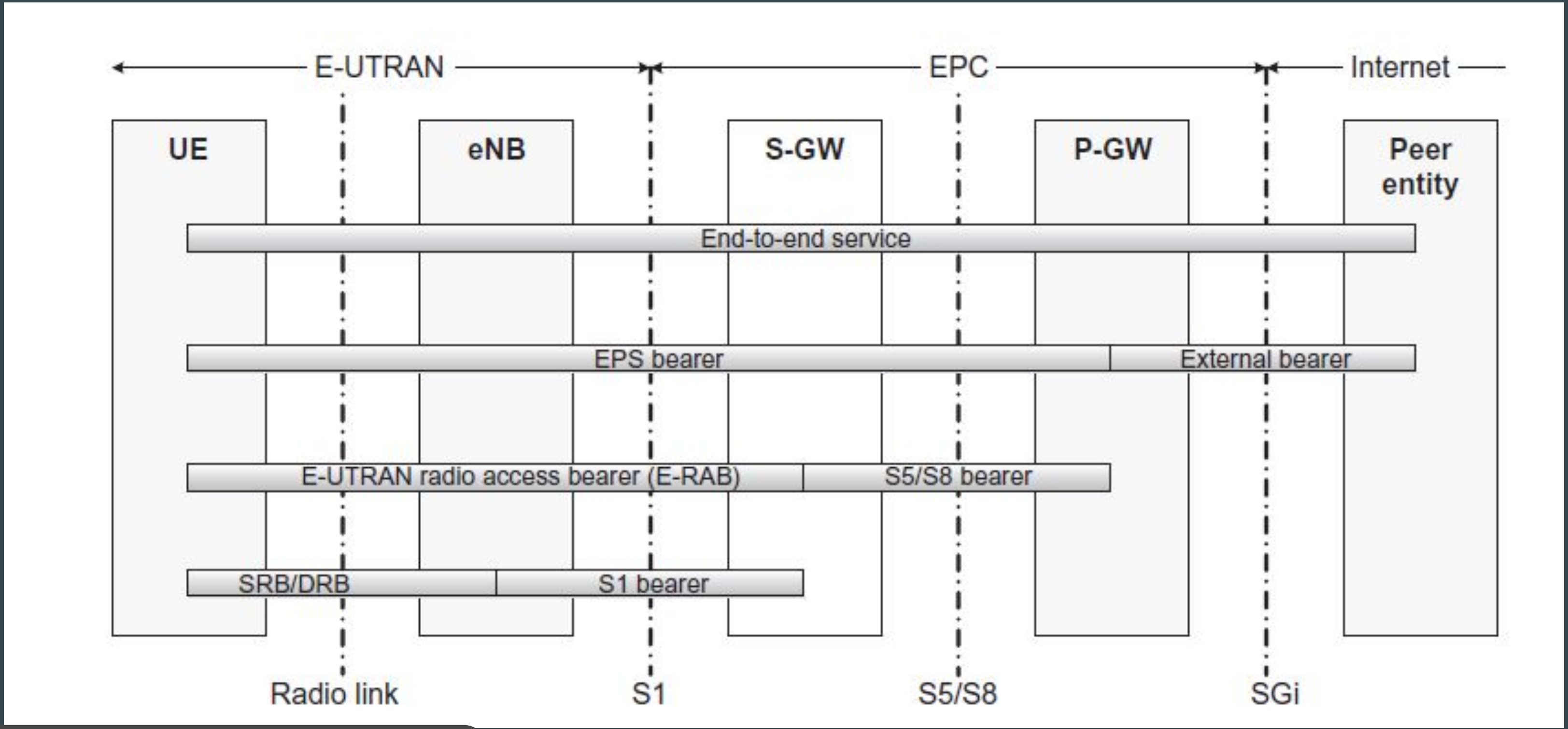
Home Subscriber Server:

- Storage of Sub Data (Auth keys, QoS profile, APN profile etc.).
- Address of currently serving MME, TA

PDN Gateway:

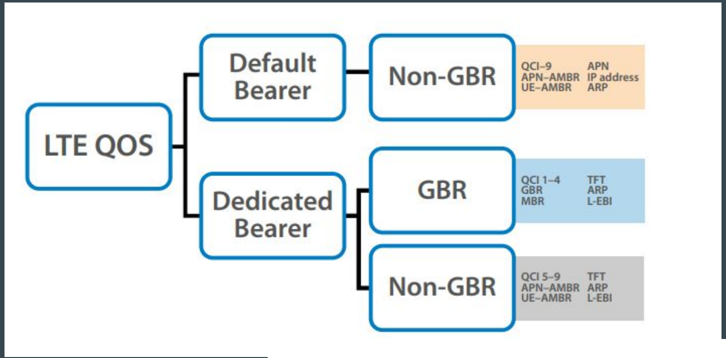
- Lawful Intercept
- IP address allocation
- Transport level marking for DL
- Downlink rate enforcement based on AMBR (Aggregate Maximum Bit Rate)
- Accounting per UE

Network Architecture in LTE contd:



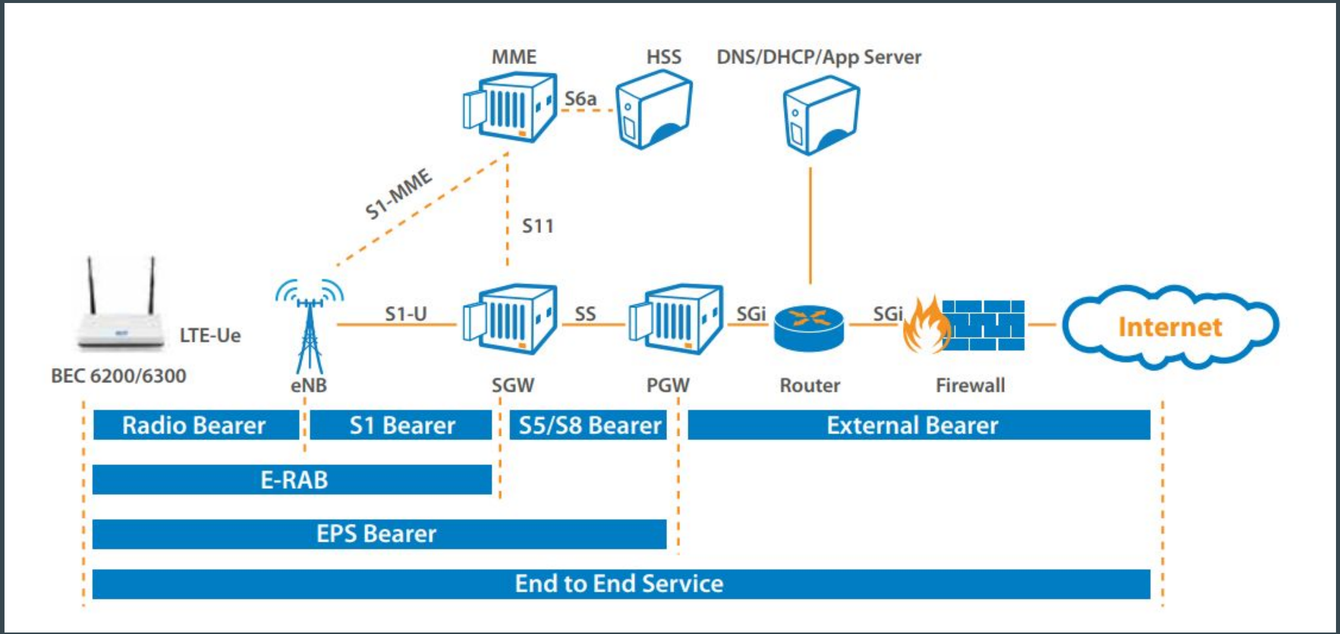
Each Bearer can have specific QoS requirements.

Network Architecture in LTE contd:



QCI	Bearer Type	Priority	Packet Delay	Packet Loss	Example
1	GBR	2	100 ms	10	VOIP Call
2		4	150 ms	10	Video Call
3		3	50 ms		Online Gaming (Real Time)
4		5	300 ms	10	Video Streaming
5	Non-GBR	1	100 ms		IMS Signaling
6		6	300 ms		Video, TCP based services e.g. email, chat, ftp etc.
7		7	100 ms	10	Voice, Video, Interactive gaming
8		8	300 ms	10	Video, TCP based services e.g. email, chat, ftp etc.
9		9			

Network Architecture in LTE contd:



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Interfaces in LTE Network

Interfaces in LTE

- What is an interface ?

Interface represents a channel on which 2 network entities exchange information.

- Why do we need interfaces ?

Interfaces are needed in LTE to deliver information (signaling or user data) for a subscriber or network element.

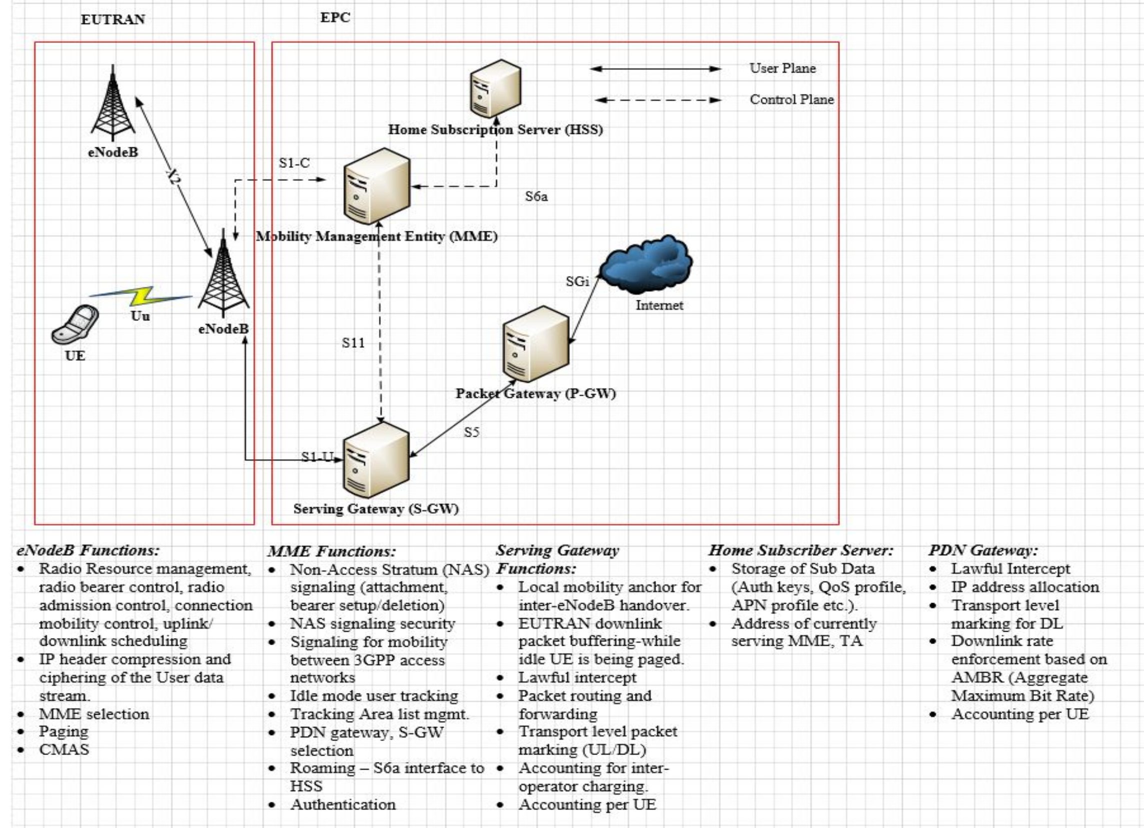
- Who defines these interfaces ?

The various network interfaces are defined by 3GPP. All network vendors or manufacturers are required to comply to these standards.

- Do these interfaces remain static ?

No. Depending on new capabilities and requirements 3GPP continues to make changes to the interface standards. However in most cases they are backward compatible.

Interfaces in LTE contd:

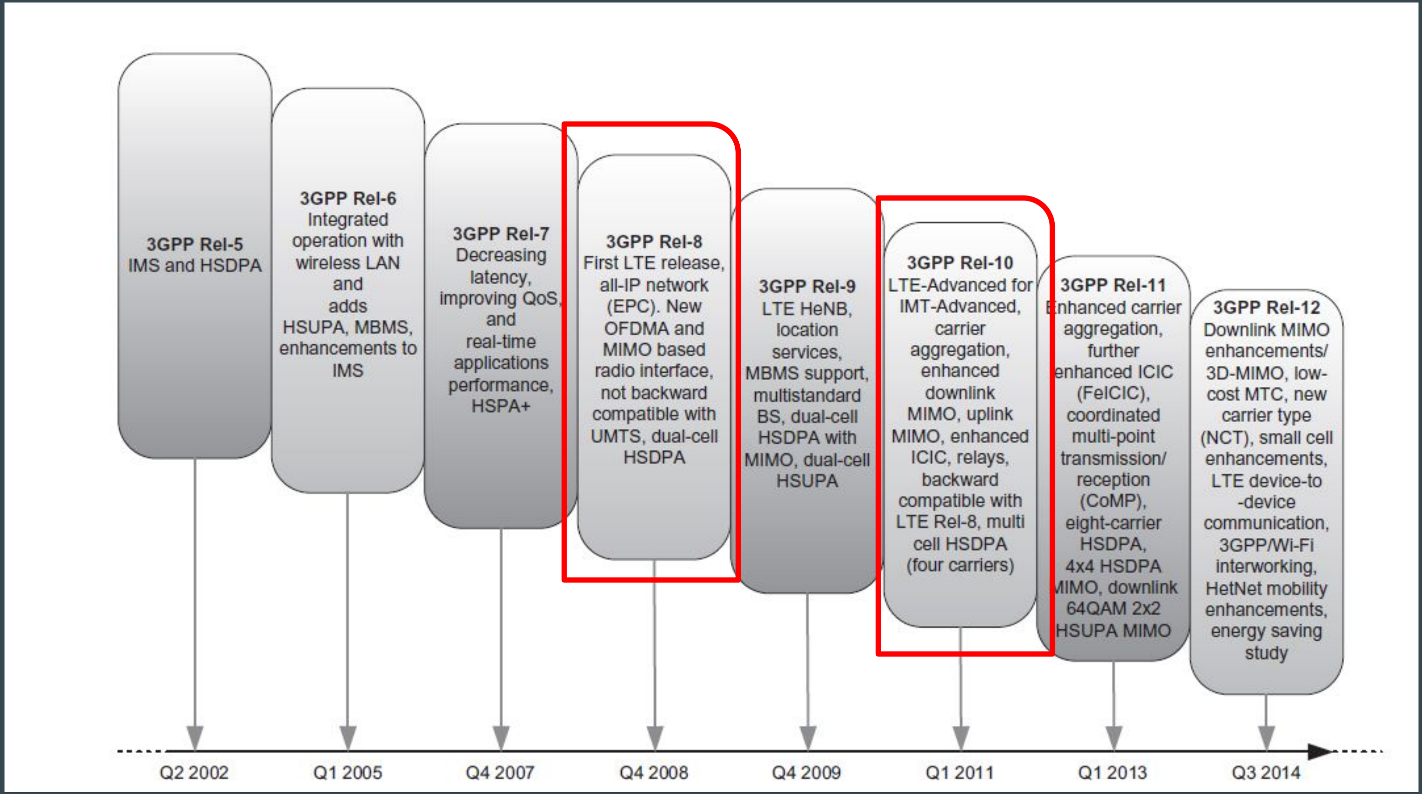


3GPP References:

- EUTRAN
  TS 36.401,36.300,23.002
- S1 Interface
  TS 36.41x series, TS 29.274, 24.301
- X2 Interface
  TS 36.42x series
- MME functions and interfaces
  TS 23.401, 23.402, 23.002
- S10/S11
  TS 29.274
- S6a
  TS 29.272
- SGW and PGW functions
  TS 23.401, 23.402, 23.002
- S5/S8 interface
  TS 29.274, 29.275
- SGi Interface
  TS 29.061

http://www.3gpp.org/specifications/specifications

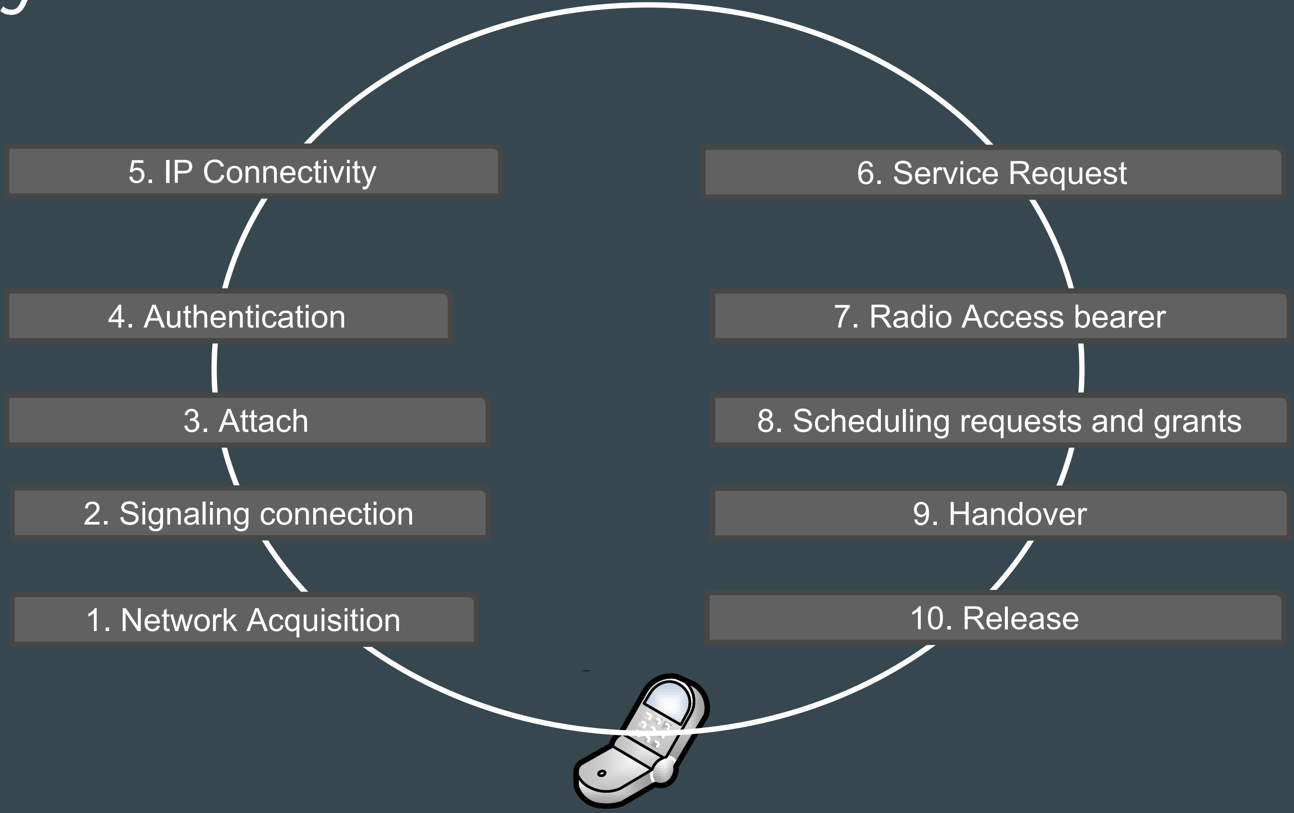
Evolution in LTE



*Source – 3GPP

Life Cycle of a UE

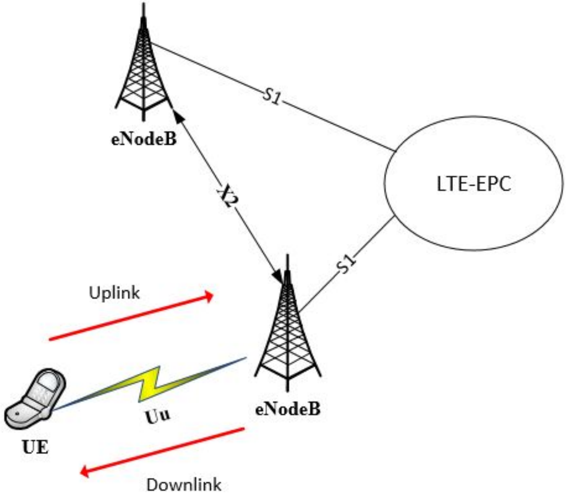
Life Cycle of a UE



LTE-RAN Overview

Radio Access Network:

- Interfaces – Uu, S1 and X2
- Scalable BW – 1.4, 3, 5, 10, 15, 20 MHz
- Latency - < 100 msec (C-Plane) and < 5 msec (U-Plane)
- Mobility support for low (< 15 Km/h) and high speeds (upt 500 Km/h)
- Downlink uses OFDM (orthogonal Frequency division multiplexing)
- Uplink uses SC-FDMA (single carrier frequency division multiple Access)



E-UTRA
- Downlink: 300 Mbps
- Uplink: 75 Mbps
- OFDM and MIMO

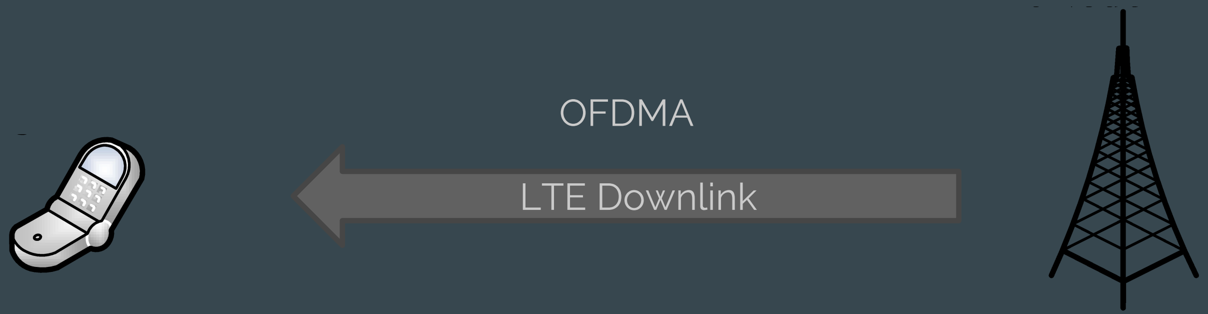
Using 20 MHz

LTE Frequency Bands.

FDD LTE BANDS & FREQUENCIES					
LTE BAND NUMBER	UPLINK (MHZ)	DOWNLINK (MHZ)	WIDTH OF BAND (MHZ)	DUPLEX SPACING (MHZ)	BAND GAP (MHZ)
1	1920 - 1980	2110 - 2170	60	190	130
2	1850 - 1910	1930 - 1990	60	80	20
3	1710 - 1785	1805 -1880	75	95	20
4	1710 - 1755	2110 - 2155	45	400	355
5	824 - 849	869 - 894	25	45	
6	830 - 840	875 - 885	10	35	
7	2500 - 2570	2620 - 2690	70	120	
8	880 - 915	925 - 960	35	45	
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	
10	1710 - 1770	2110 - 2170	60	400	
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	
12	698 - 716	728 - 746	18	30	
13	777 - 787	746 - 756	10	-31	
14	788 - 798	758 - 768	10	-30	
15	1900 - 1920	2600 - 2620	20	700	
16	2010 - 2025	2585 - 2600	15	575	
17	704 - 716	734 - 746	12	30	
18	815 - 830	860 - 875	15	45	
19	830 - 845	875 - 890	15	45	
20	832 - 862	791 - 821	30	-41	
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	
22	3410 - 3500	3510 - 3600	90	100	
23	2000 - 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 - 1915	1930 - 1995	65	80	15
26	814 - 849	859 - 894	30 / 40		10
27	807 - 824	852 - 869	17	45	28
28	703 - 748	758 - 803	45	55	10
29	n/a	717 - 728	11		
30	2305 - 2315	2350 - 2360	10	45	35
31	452.5 - 457.5	462.5 - 467.5	5	10	5

TDD LTE BANDS & FREQUENCIES		
LTE BAND NUMBER	ALLOCATION (MHZ)	WIDTH OF BAND (MHZ)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 - 2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200
44	703 - 803	100

Radio Access network contd.



High Spectral Efficiency

Time and frequency allocation

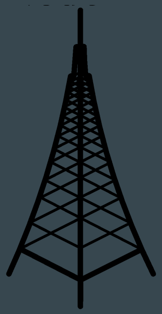
Robust against Multipath

Support for MIMO

Radio Access network contd.

SC-FDMA

LTE Uplink

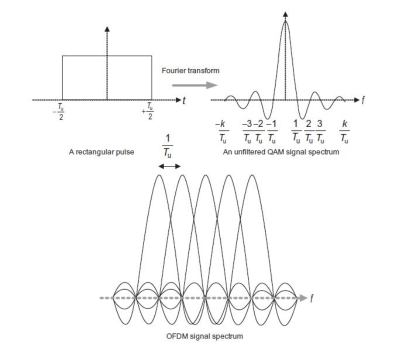


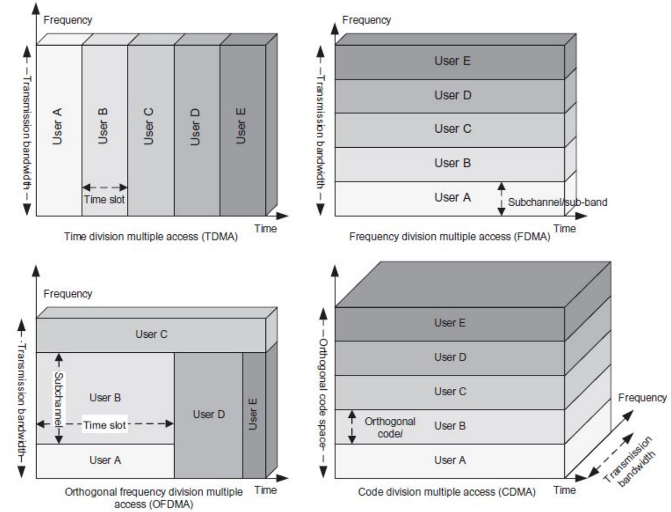
Reduced
Peak-to-average Power
Ratio

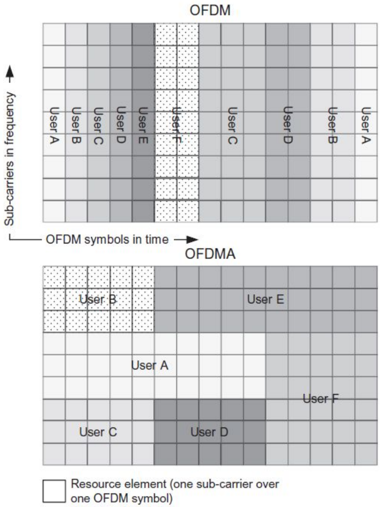
Better Cell-edge performance
due to low PAPR

OFDMA

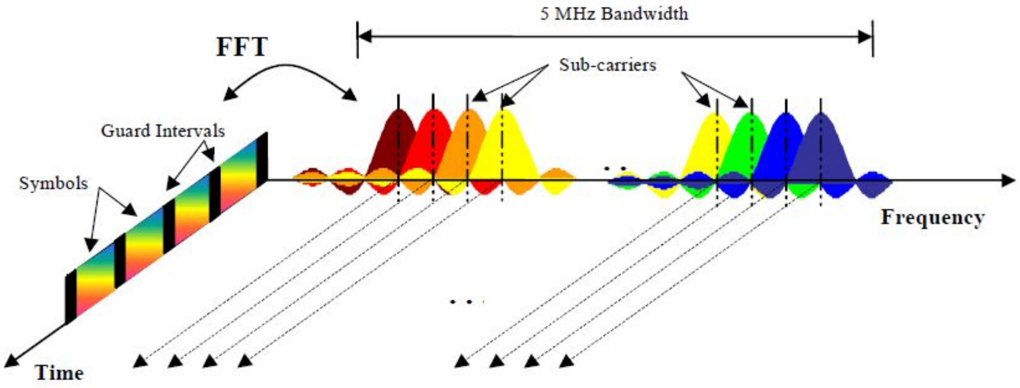
- Several multiple access techniques exist – TDMA, FDMA, CDMA, OFDMA
- OFDMA is not new and has existed for quite some time.
- The idea is to divide entire bandwidth into chunks called subcarriers. These subcarriers can then be allocate in time and frequency domain.
- Subc al in nature.







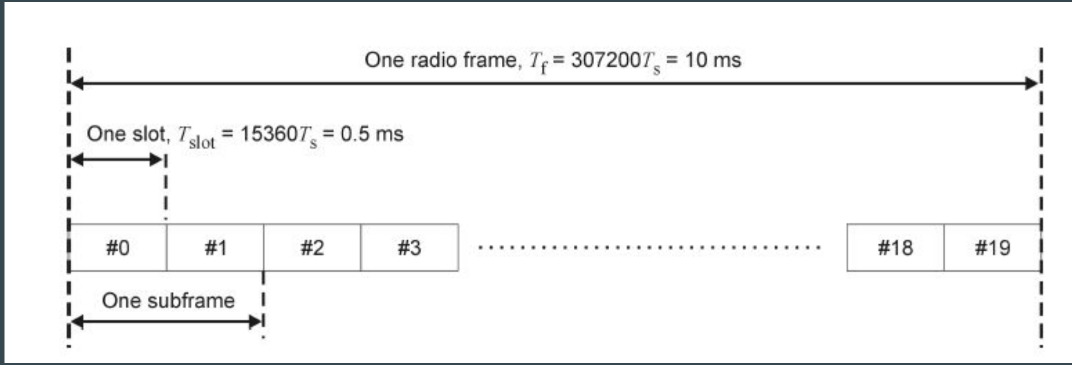
OFDMA Contd.

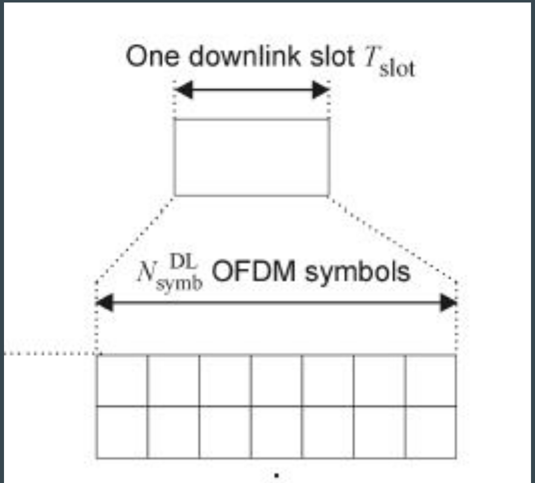


- LTE provides QPSK, 16QAM, 64QAM as downlink modulation schemes
- Cyclic prefix is used as guard interval, different configurations possible:
  - Normal cyclic prefix with 5.2 µs (first symbol) / 4.7 µs (other symbols)
  - Extended cyclic prefix with 16.7 µs
- 15 kHz subcarrier spacing
- Scalable bandwidth

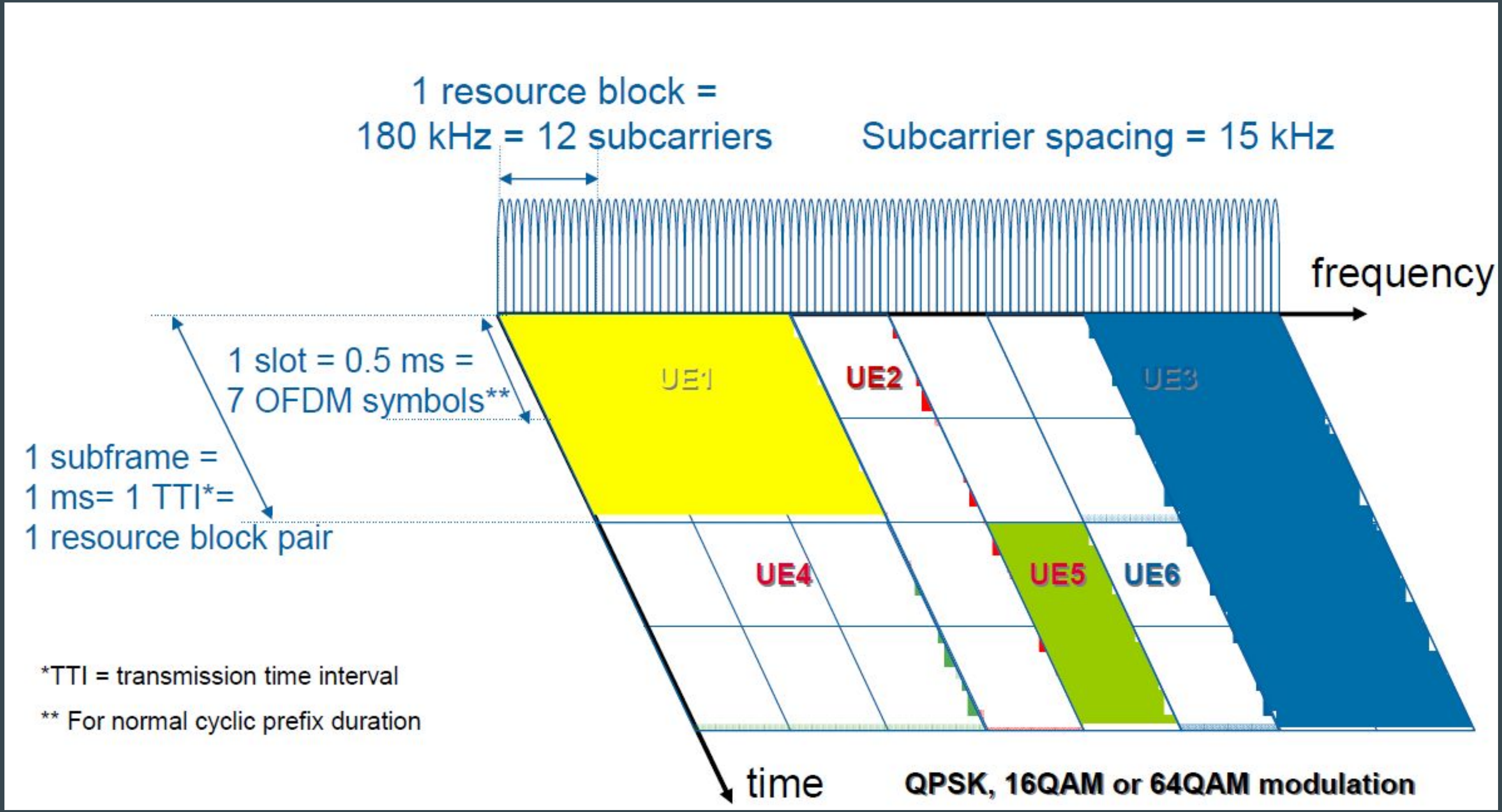
OFDMA Contd.

- In LTE transmission happens every 1 msec a.k.a TTI (transmit time interval)
- Concepts –
- Slot
- Symbol
- Sub frame
- Radio Frame



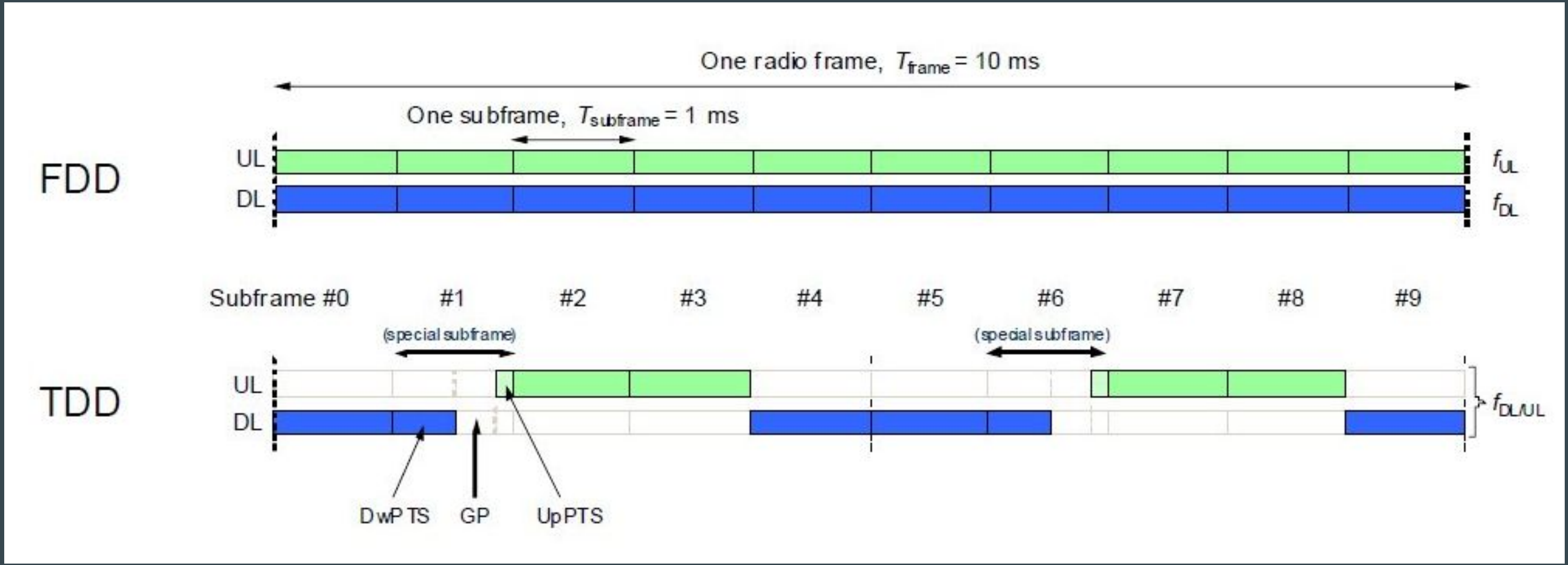


OFDMA Contd.



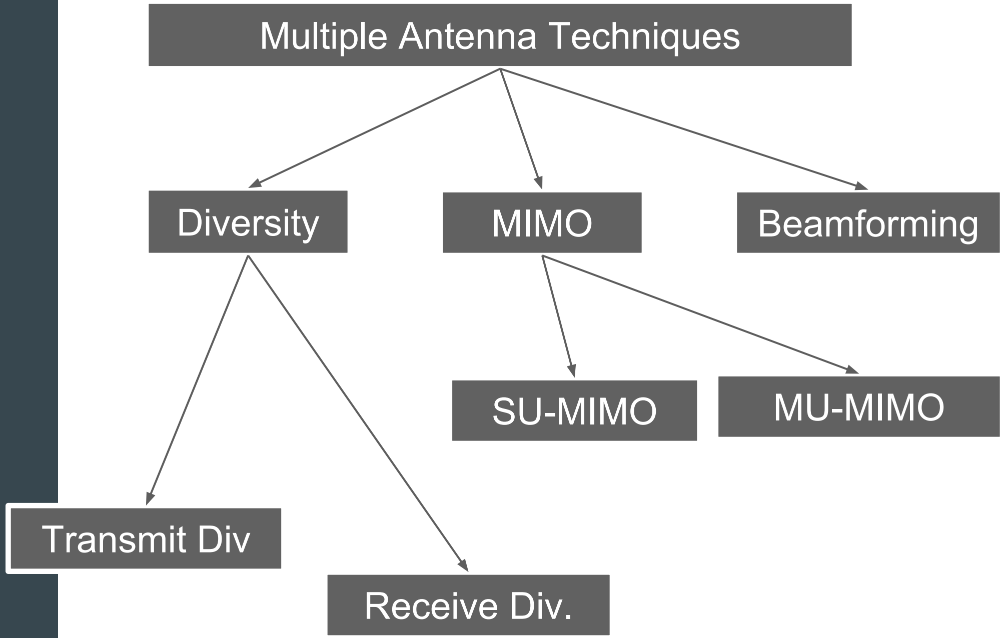
1 resource block =
180 kHz = 12 subcarriers
Subcarrier spacing = 15 kHz
frequency
1 slot = 0.5 ms =
7 OFDM symbols**
1 subframe =
1 ms= 1 TTI*=
1 resource block pair
UE1
UE2
UE3
UE4
UE5
UE6
*TTI = transmission time interval
** For normal cyclic prefix duration
time
QPSK, 16QAM or 64QAM modulation

LTE FDD vs TDD



Multiple Antenna Techniques in LTE

- Transmit and Receive diversity
- SU-MIMO and MU-MIMO
- Beamforming

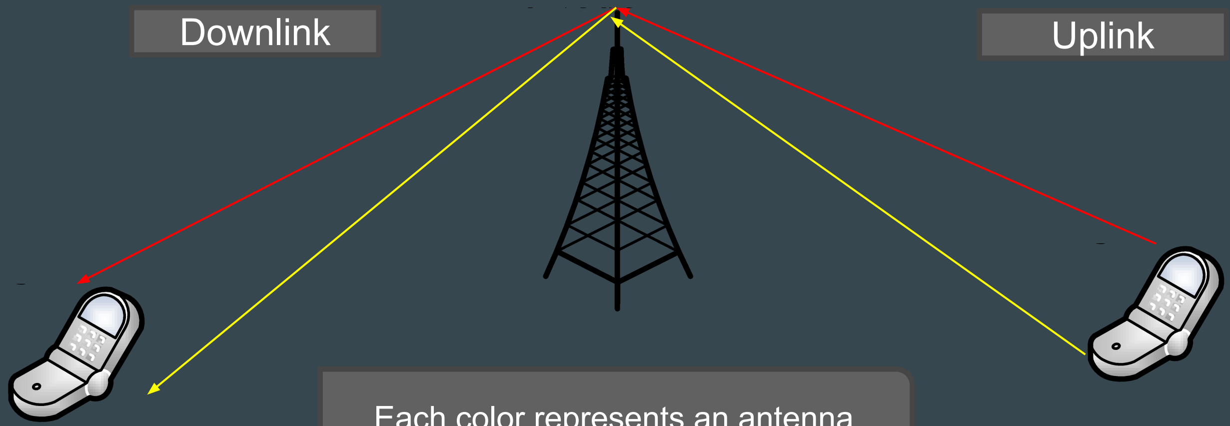


Multiple Antenna Technologies contd.

2x2 Antenna System

Downlink

Uplink



Each color represents an antenna

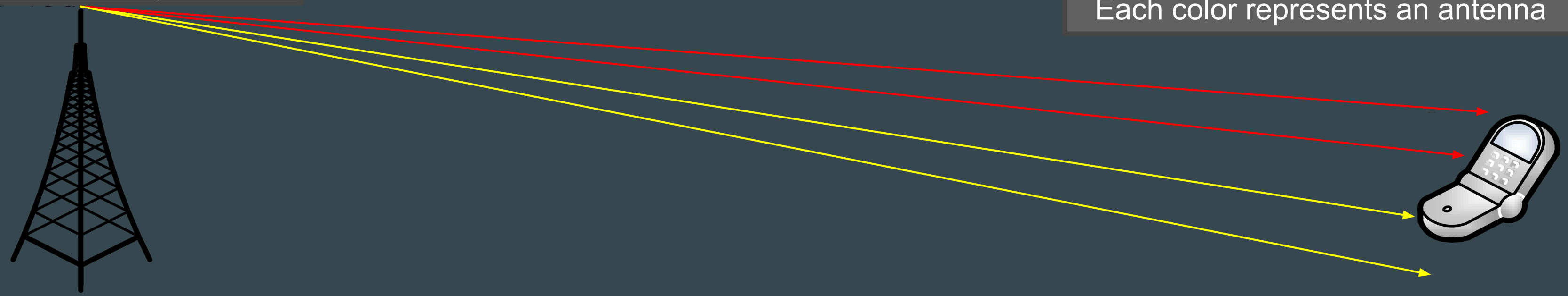
Intelligent use of space, time and frequency to send multiple copies of signal at receiver (UE)

Multiple antennas at receiver to leverage the signal variation in space by suitable combing copies of signal sent by UE

Multiple Antenna Technologies contd.
SU-MIMO

Downlink

2x2 Antenna System



Each color represents an antenna

Bit Stream for UE is divided among Antenna elements. Each element sends a different Bit stream effectively doubling the throughput

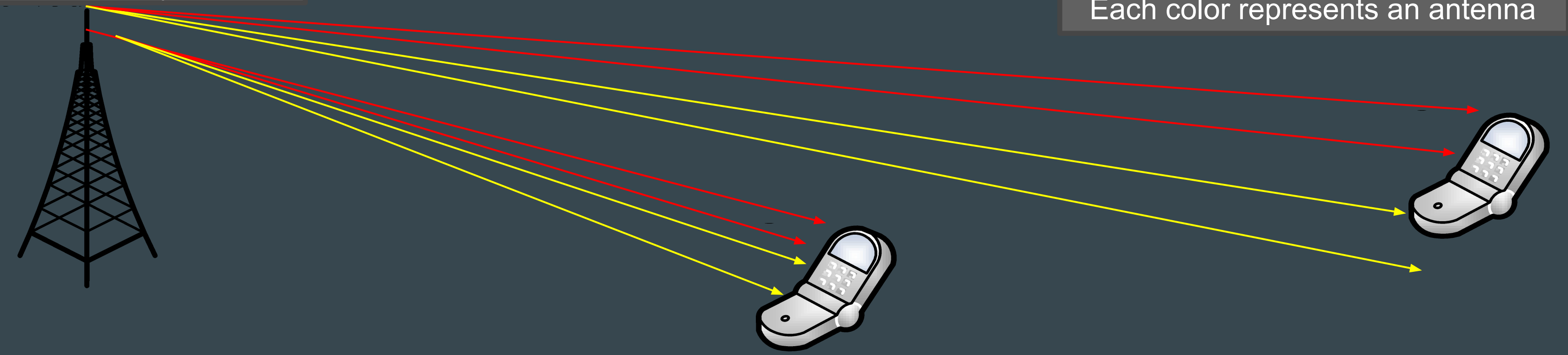
UE receives bit streams from both antennas and combines them to receive data at twice the speed compared to TxD

Multiple Antenna Technologies contd. MU-MIMO

Downlink

2x2 Antenna System

Each color represents an antenna



Bit Streams for UEs is divided among Antenna elements. Each element sends a different Bit stream effectively doubling the throughput

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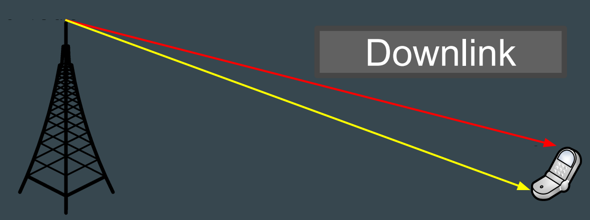
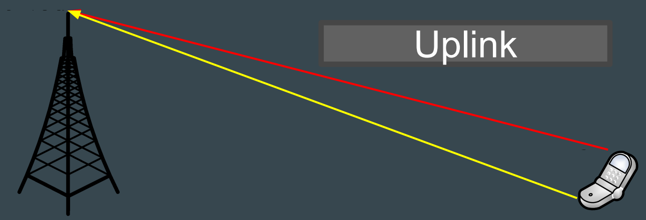
Physical Channels in LTE:

What is a channel ? It is like a path that has a specific function.

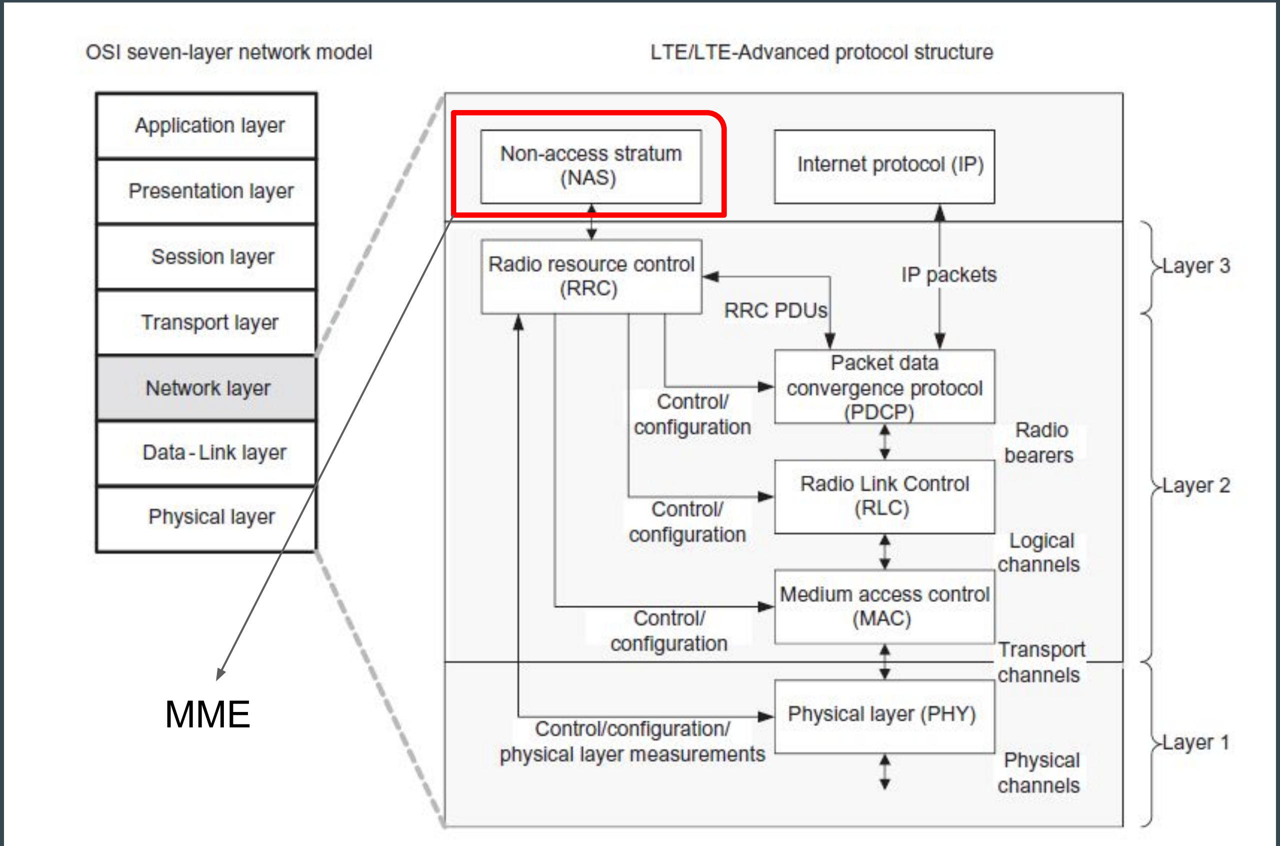




1. Physical broadcast Channel – Transmits broadcast and system overhead information.
2. Physical Downlink Control Channel. Transmits control messages for UE (power control, scheduling assignments)
3. Physical Downlink Shared Channel. Transmits user data.
4. Physical Control Format Indicator Channel. Indicates number of OFDM symbols used for control information.
5. Physical Hybrid Indicator. Transmits ACK/NACk for uplink data.

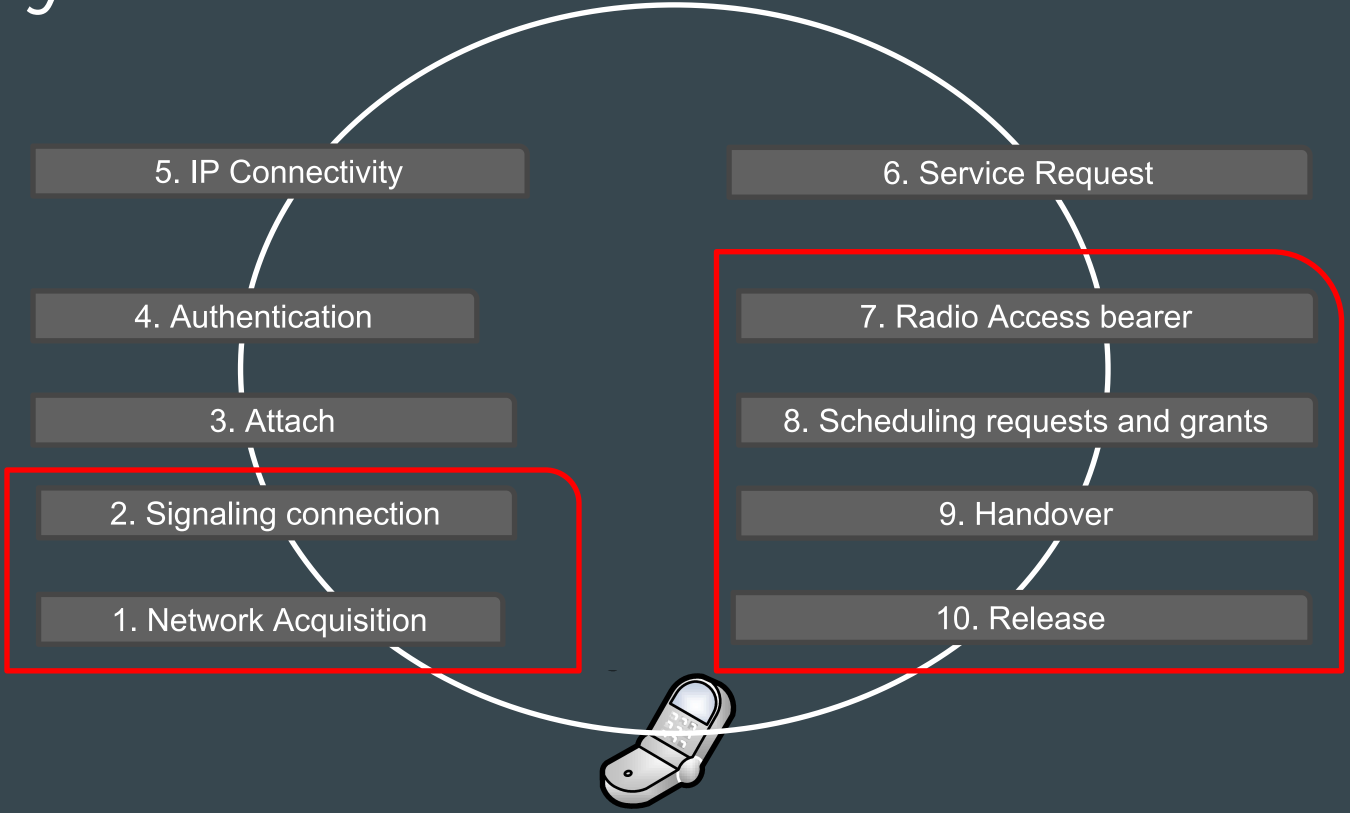
1. Physical Random Access Channel. Carries RA request from UE.
2. Physical Uplink Shared Channel. Carries Uplink data.
3. Physical Uplink Control Channel. Carrier information re channel quality, acknowledgements, scheduling requests

Protocol Stack in LTE:

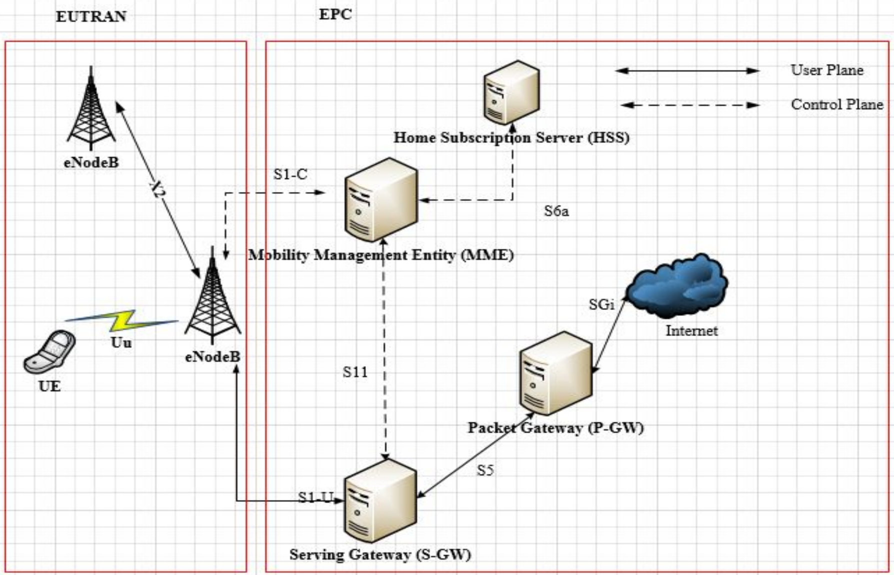


LTE-EPC Overview

Life Cycle of a UE



LTE-EPC:



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PDN Gateway:

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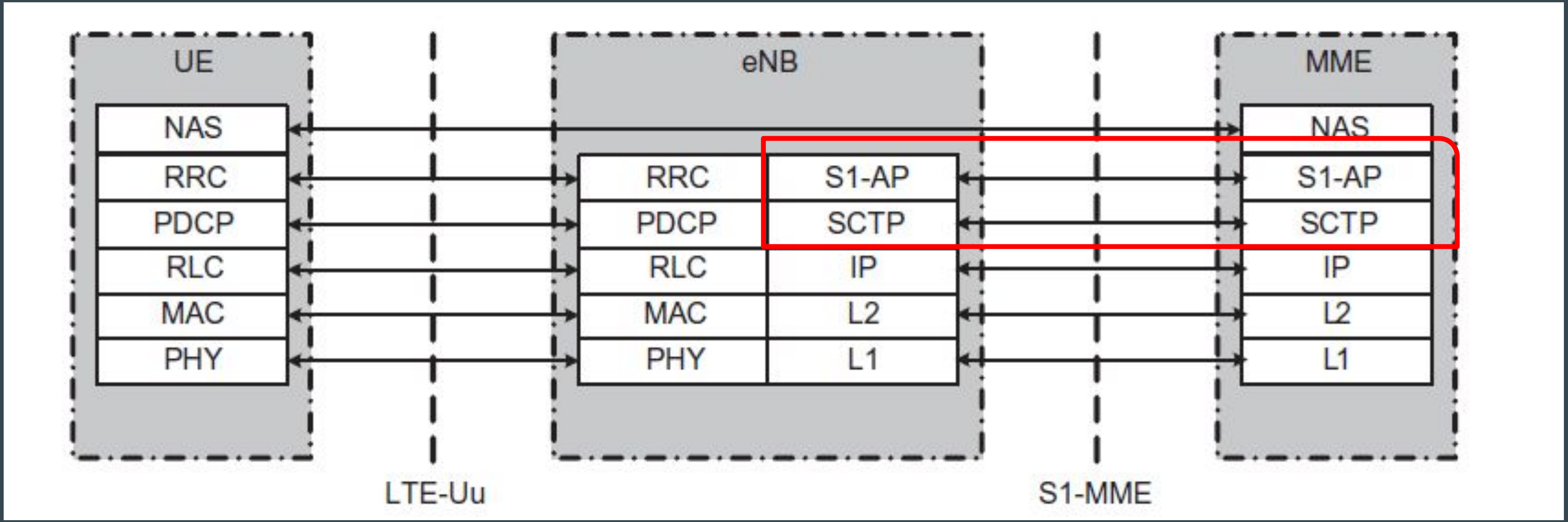
- IP address allocation
- Transport level marking for DL
- Downlink rate enforcement based on AMBR (Aggregate Maximum Bit Rate)
- Accounting per UE

Mobility Management Entity (MME):

MME is responsible for the following functions in EPC –

- Managing and storing UE contexts
- Generating temporary UE Identifiers
- Managing Idle state mobility
- Distributing Paging messages
- Controlling Security functions such as authentication
- Controlling EPS bearers

Mobility Management Entity (MME):

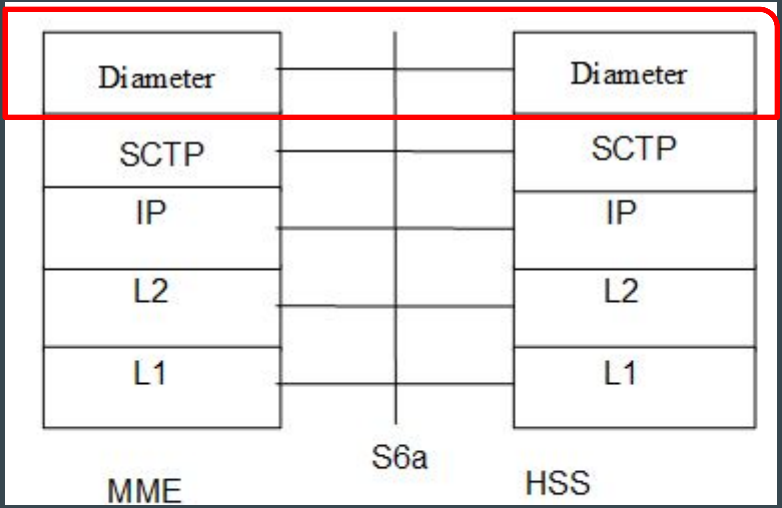


SCTP (Stream control transmission protocol) is a tunneling protocol used between eNodeB and MME. S1-AP uses SCTP.

Home Subscriber Server (HSS):

HSS is responsible for the following functions in EPC –

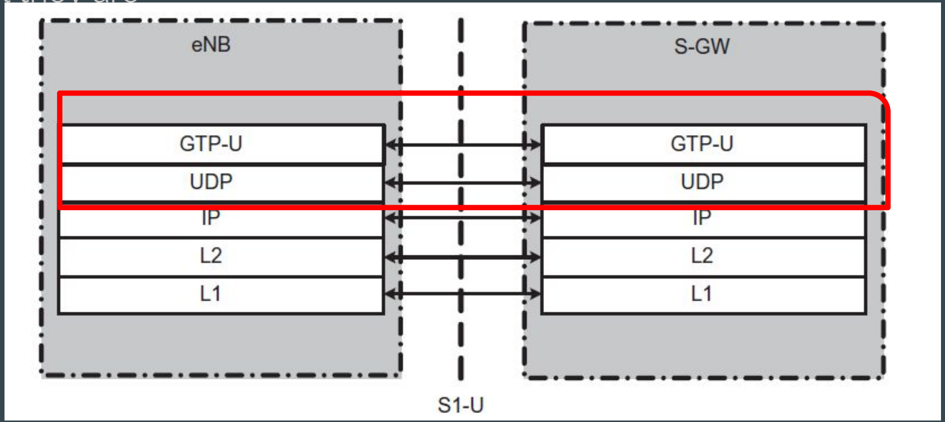
- Master database that stores subscription related information to support call control and session management entities
- Storehouse for subscription profiles and user Identities
- Involved in User authentication
- Works with MME to authenticate user



Serving Gateway (S-GW):

SGW is responsible for the following functions in EPC –

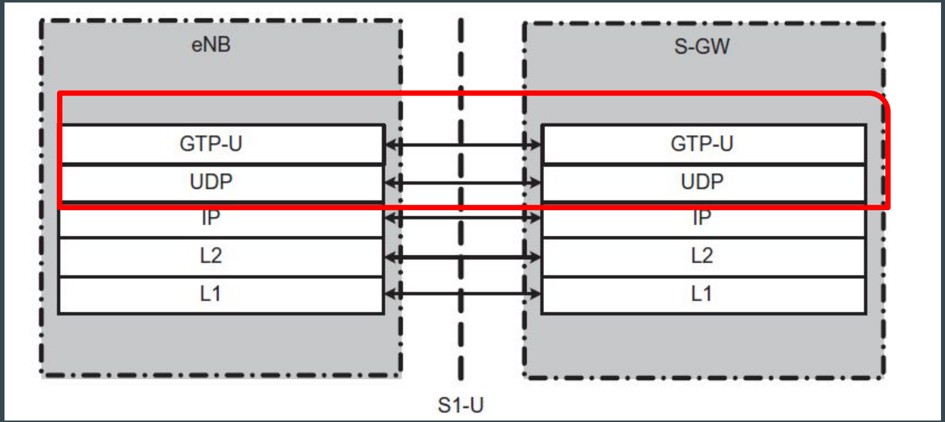
- Anchor for inter-enodeb handover in LTE
- Buffers data in downlink for Idle mode Users until they are In connected state
- Generated Usage records which can be used for billing



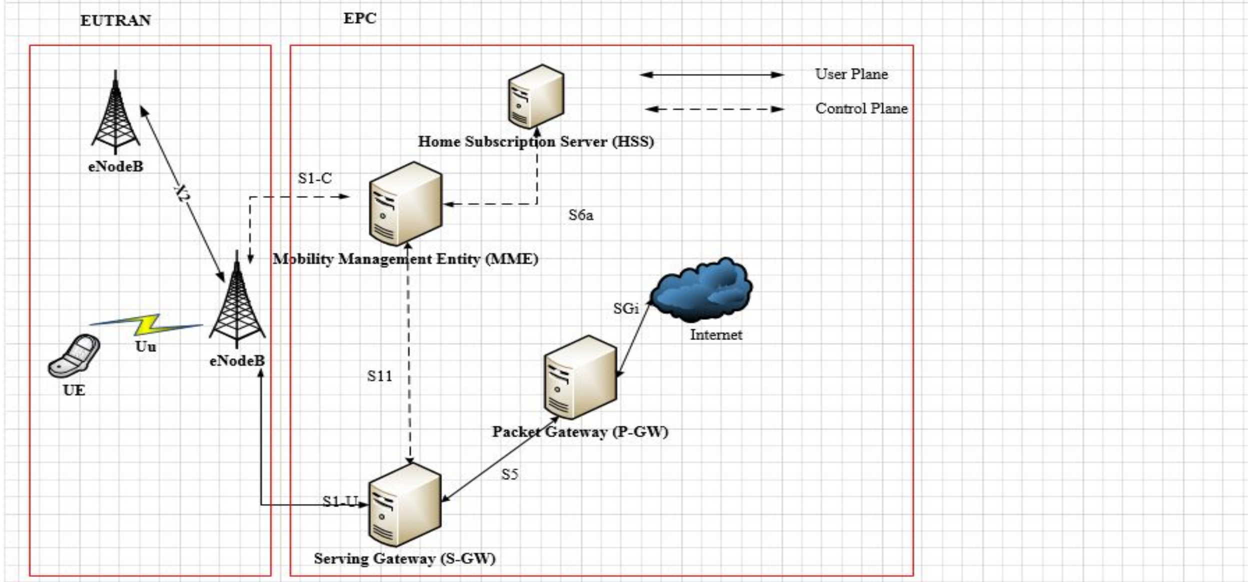
Packet Gateway (P-GW):

PGW is responsible for the following functions in EPC –

- Acts as router for the UE traffic
- Allocated IP address to the UE/bearer
- Performs DSCP/QoS marking for UE packets



LTE-EPC:



eNodeB Functions:
- Radio Resource management, radio bearer control, radio admission control, connection mobility control, uplink/ downlink scheduling
- IP header compression and ciphering of the User data stream.
- MME selection
- Paging
- CMAS

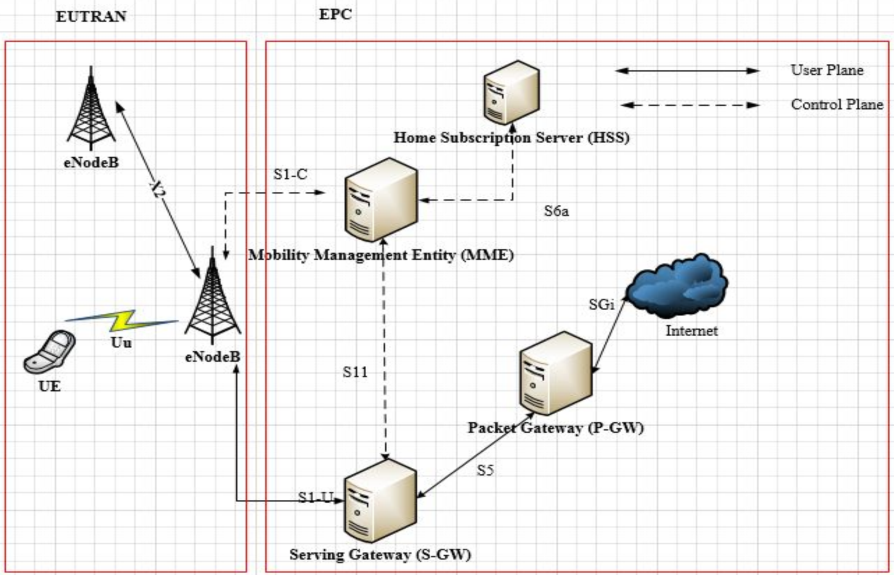
MME Functions:
- Non-Access Stratum (NAS) signaling (attachment, bearer setup/deletion)
- NAS signaling security
- Signaling for mobility between 3GPP access networks
- Idle mode user tracking
- Tracking Area list mgmt.
- PDN gateway, S-GW selection
- Roaming – S6a interface to HSS
- Authentication

Serving Gateway Functions:
- Local mobility anchor for inter-eNodeB handover.
- EUTRAN downlink packet buffering-while idle UE is being paged.
- Lawful intercept
- Packet routing and forwarding
- Transport level packet marking (UL/DL)
- Accounting for inter-operator charging.
- Accounting per UE

Home Subscriber Server:
- Storage of Sub Data (Auth keys, QoS profile, APN profile etc.).
- Address of currently serving MME, TA

PDN Gateway:
- Lawful Intercept
- IP address allocation
- Transport level marking for DL
- Downlink rate enforcement based on AMBR (Aggregate Maximum Bit Rate)
- Accounting per UE

LTE-EPC:



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- Accounting per UE

Thanks

LTE-UE Categories

UE Categories:

- UE category of a UE represents a set of functions/capablities the UE is capable of performing.
- Categories are defined by 3GPP in the document 3GPP TS 36.306
- A single UE category defines both the uplink and downlink capabilities. This is different from UMTS which uses separate categories for HSDPA and HSUPA
- UE capabilities are transferred to the EUTRAN during the “UE Capability information exchange” procedure.

UE Categories:

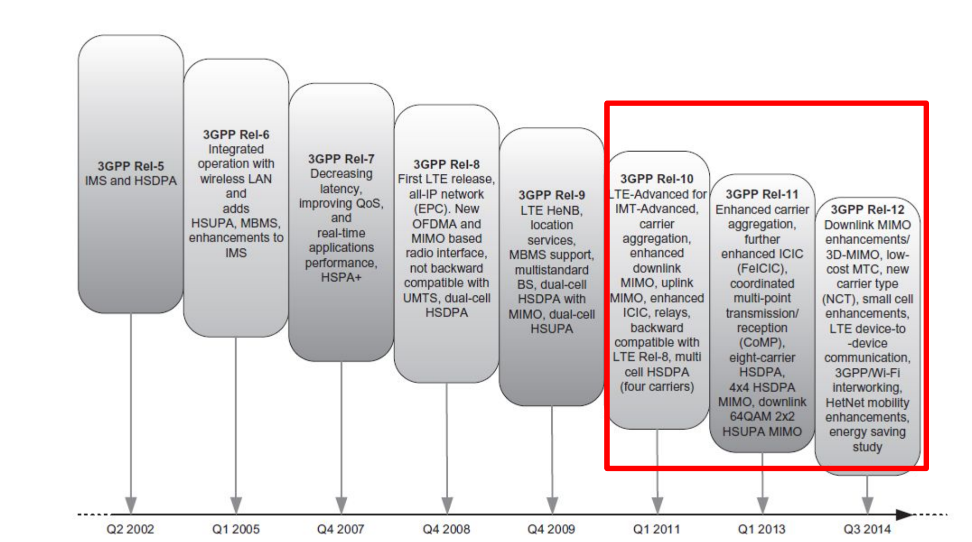
UE Category	Peak Data Rate Downlink/ Uplink (Mbps)	Maximum Number of DL-SCH Transport Block Bits Received within a TTI	Maximum Number of Bits of a DL-SCH Transport Block Received within a TTI	Total Number of Soft Channel Bits in the Downlink	Maximum Number of Supported Layers for Spatial Multiplexing in the Downlink	Maximum Number of UL-SCH Transport Block Bits Transmitted within a TTI	Maximum Number of Bits of a UL-SCH Transport Block Transmitted within a TTI	Support for 64QAM in Uplink	Total Layer 2 Buffer Size (Bytes)	Maximum Number of Bits of an MCH Transport Block Received within a TTI
Category 1	10/5	10,296	10,296	250,368	1	5160	5160	No	150,000	10,296
Category 2	50/25	51,024	51,024	1,237,248	2	25,456	25,456	No	700,000	51,024
Category 3	100/50	102,048	75,376	1,237,248	2	51,024	51,024	No	1,400,000	75,376
Category 4	150/50	150,752	75,376	1,827,072	2	51,024	51,024	No	1,900,000	75,376
Category 5	300/75	299,552	149,776	3,667,200	4	75,376	75,376	Yes	3,500,000	75,376
Category 6	300/50	301,504	149,776 (4 layers) 75,376 (2 layers)	3,654,144	2 or 4	51,024	51,024	No	3,300,000	(75,376)
Category 7	300/150	301,504	149,776 (4 layers) 75,376 (2 layers)	3,654,144	2 or 4	102,048	51,024	No	3,800,000	(75,376)
Category 8	1200/600	2,998,560	299,856	35,982,720	8	1,497,760	149,776	Yes	4,220,0000	(75,376)

LTE-Advanced Overview

LTE Advanced:

LTE-Advanced (LTE Rel 10/11) extended the capabilities of LTE Rel-8/9 by introducing new features -

1. Carrier Aggregation
2. Enhanced Multi-Antenna techniques (SU-MIMO and MU-MIMO) – Discussed in section on multiple antenna techniques before.
3. Coordinated Multi-point operation (COMP)
4. Enhancements to UE Categories



Carrier Aggregation:

- LTE Rel-8/9 specified system bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz to meet different spectrum deployment requirements. Support of wider bandwidths up to 100 MHz was one of the distinctive features of IMT-Advanced systems. The IMT-Advanced systems targeted peak data rates in excess of 1 Gbps for low mobility and 100 Mbps for high mobility scenarios. In order to support wider transmission bandwidths, LTE Rel-10 introduced the carrier aggregation concept where two or more component carriers with arbitrary bandwidths belonging to the same or different frequency bands could be aggregated.

- Enables operators to use different chunks of spectrum in combination to deliver greater throughputs to UEs.

- Enables network operator to use fragmented pieces of spectrum. Not all operators are spectrum rich.

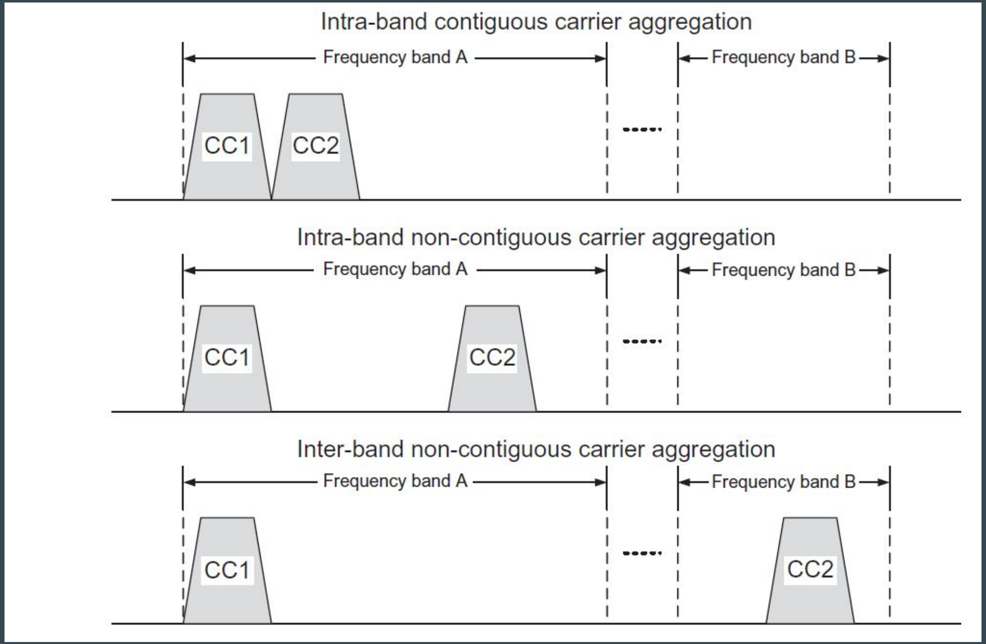
- Operators can use up to 100 MHz of combine bandwidth

Carrier Aggregation:

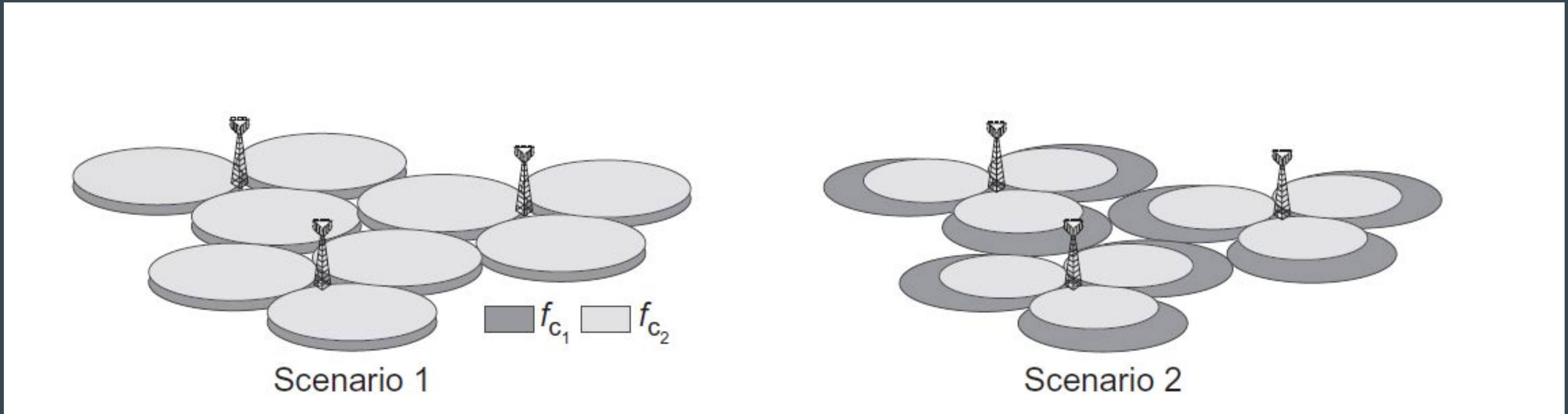
Deployment Scenarios:

- Intra-band contiguous carrier aggregation
- Intra-band non-contiguous carrier aggregation
- Inter-band non-contiguous carrier aggregation

Each of the CC (Component Carrier) can be 1.4,3,5,10,15 or 20 MHz.



Carrier Aggregation:

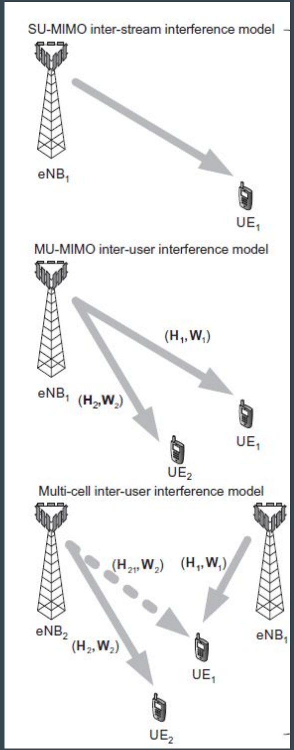


Fc1 and fc2 are 2 frequencies with similar coverage

Fc1 and fc2 are 2 frequencies with different coverage

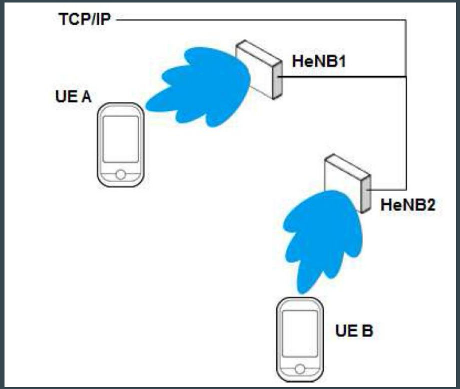
Coordinated Multipoint (COMP):

- We need comp to combat effects of interference
- An UE can experience Interference even when MIMO is being used.
  - SU-MIMO (Inter Stream interference)
  - MU-MIMO (inter User interference)
- Interference can be from neighboring cells/sites as well.
- Quality of a channel is depicted by SINR (Signal to interference plus noise ratio (SINR)
- SINR = (Signal)/(Interference + Noise)
- High SINR means better quality
- Low SINR means low quality
- As SINR decreases so does throughput therefore interference can impact throughput => implies we need interference control



Coordinated Multipoint (COMP):

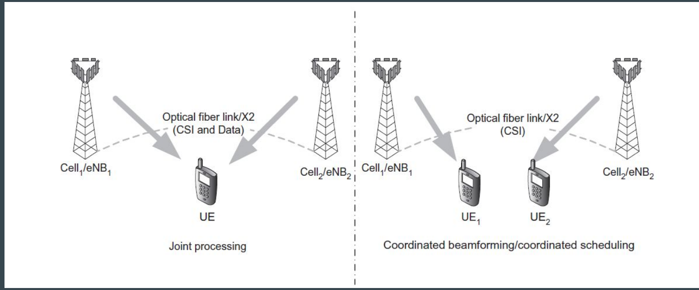
- COMP can be implemented in DL or UL
- Each of the these implementations is meant to reduce interference.

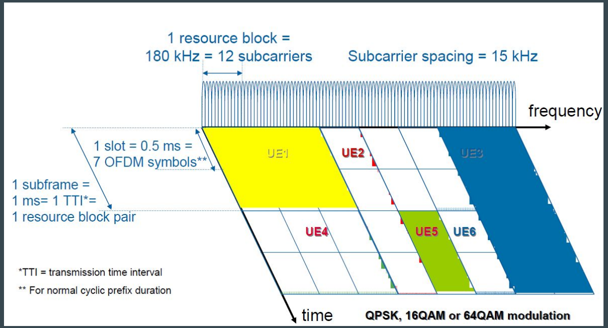


DL COMP

Join Processing

Coordinated Scheduling/Beamforming





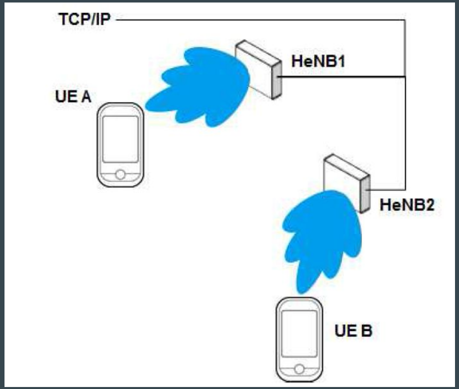
Coordinated Multipoint (COMP):

- Each of the these implementations is meant to reduce interference.

UL COMP

Joint Reception

Coordinated Scheduling/Beamforming



UE Categories – Updated!

Category		3GPP release	Downlink: Maximum number of DL-SCH transport block bits received within a TTI	(Mbit/s)	Downlink: Maximum number of bits of a DL-SCH transport block received within a TTI	Downlink: Total number of soft channel bits	Downlink: Maximum number of supported layers for spatial multiplexing in DL	Downlink: Support for 256QAM in DL	Uplink: Maximum number of UL-SCH transport block bits transmitted within a TTI	(Mbit/s)	Uplink: Maximum number of bits of an UL-SCH transport block transmitted within a TTI	Uplink: Support for 64QAM in UL
0		Rel 12	1000	1	1000	25344	1	No	1000	1	1000	No
1		Rel 8	10296	10	10296	250368	1	No	5160	5	5160	No
1bis		Rel 14	10296	10	10296	250368	1	No	5160	5	5160	No
2		Rel 8	51024	51	51024	1237248	2	No	25456	25	25456	No
3		Rel 8	102048	102	75376	1237248	2	No	51024	51	51024	No
4		Rel 8	150752	150	75376	1827072	2	No	51024	51	51024	No
5		Rel 8	299552	299	149776	3667200	4	No	75376	75	75376	Yes
6	4	Rel 10	301504	301	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	3654144	2 or 4	No	51024	51	51024	No
7	4	Rel 10	301504	301	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	3654144	2 or 4	No	102048	102	51024	No
8	5	Rel 10	2998560	2998	299856	35982720	8	No	1497760	1497	149776	Yes
9	6,4	Rel 11	452256	452	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	5481216	2 or 4	No	51024	51	51024	No
10	7,4	Rel 11	452256	452	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	5481216	2 or 4	No	102048	102	51024	No
11	9,6,4	Rel 11	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional	51024	51	51024	No
12	10,7,4	Rel 11	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional	102048	102	51024	No

Thanks

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